Geostationary Coastal and Air Pollution Events (GeoCAPE) Filter Radiometer (FR)

~ Concept Presentation~

Systems

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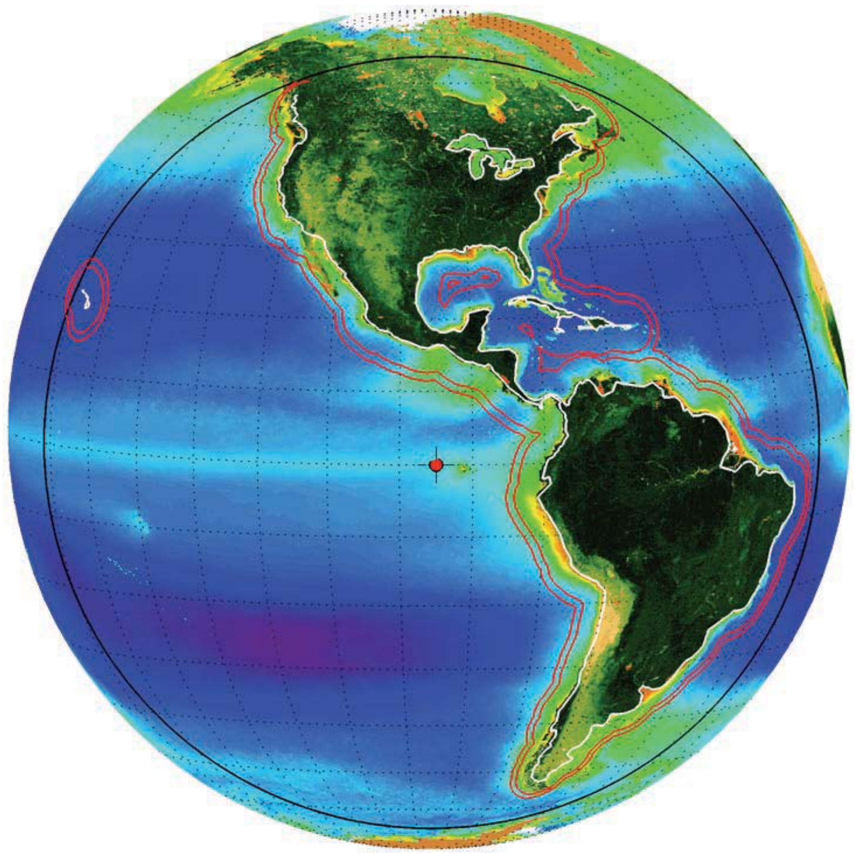
Introduction

- **The GeoCAPE Filter Radiometer (FR) Study is a different instrument type than all of the previous IDL GeoCape studies.**
- **The customer primary goals are to keep mass, volume and cost to a minimum while meeting the science objectives and maximizing flight opportunities by fitting on the largest number of GEO accommodations possible.**
  - Minimize total mission costs by riding on a commercial GEO satellite.
- **For this instrument type, the coverage rate, km^2/min, was significantly increased while reducing the nadir ground sample size to 250m. This was accomplished by analyzing a large 2d area for each integration period.**
  - The field of view will be imaged on a 4k x 4k detector array of 15um pixels.
    - Each ground pixel is spread over 2 x 2 detector pixels so the instantaneous field of view (IFOV) is 2048 X 2048 ground pixels.
  - The baseline is, for each field of view 50 sequential snapshot images are taken, each with a different filter, before indexing the scan mirror to the next IFOV. A delta would be to add additional filters.

Coastal Ocean Biology & Biogeochemistry Mission

New Science

- Diurnal Rates of processes
- Ecosystem Health
- Carbon Fluxes
- UV radiances
    - Colored Dissolved Organic Matter - CDOM
    - Absorbing Aerosols
- Track Hazards
    - Oil Spills
    - Harmful Algal Blooms
- Advanced atmospheric correction capabilities



View from 95 W

The black outer circle encompassing much of North and South America represents the 67° sensor viewing angle, which is the approximate limit to ocean color retrievals from 95° W. The two red lines extending beyond the continental land masses represent the 375 km and 500 km (width from inland of shore [white line] to the ocean) threshold and baseline coastal region requirements. Both lines generally extend beyond the 2500 m bathymetry of the continental margin

Science Measurements

- **Top-of-the-Atmosphere radiances leading to the following retrievals:**
  - **Water-leaving radiances (Lw) from UV-NIR (350-1050 nm); a.k.a. "ocean color"**
    - Hyperspectral Lw used to retrieve surface layer aquatic optical properties (absorption and scattering), constituents (chlorophyll, Colored Dissolved Organic Matter, phytoplankton biomass, dissolved and particulate organic carbon, phytoplankton diversity, etc.) and rate processes (photosynthesis, photo-oxidation, etc.) in coastal and ocean waters.
  - **Atmospheric corrections for ocean color**
    - SWIR band radiances for atmospheric corrections over turbid waters (ocean is black or nearly black so one can quantify aerosol contributions exclusively) - minimum of 2 bands (1020, 1245, 1640, 2135 nm)
      - The baseline for this study included the 1020, 1245 and 1640nm bands, but not the 2135nm band.
      - The 2135nm band could easily be accommodated by using 2.5um cutoff MCT instead of the 1.7um MCT in the baseline. The detector operating temperature would have to be lowered to 155K from 185K but that just means a slightly larger passive radiator.
    - Detection and quantification of absorbing and non-absorbing aerosols (350-1050 nm and SWIR bands).

S/C and LV Information

- **The instrument is to be hosted as a secondary payload on a commercial geostationary communications satellite, thus specific S/C and LV information is not available.**
  - The spreadsheet on later slides contains the specifics on engineering allocations for various platforms (mass, power, volume, telemetry)
- **The scarcest engineering resources addressed:**
  - Mass and volume

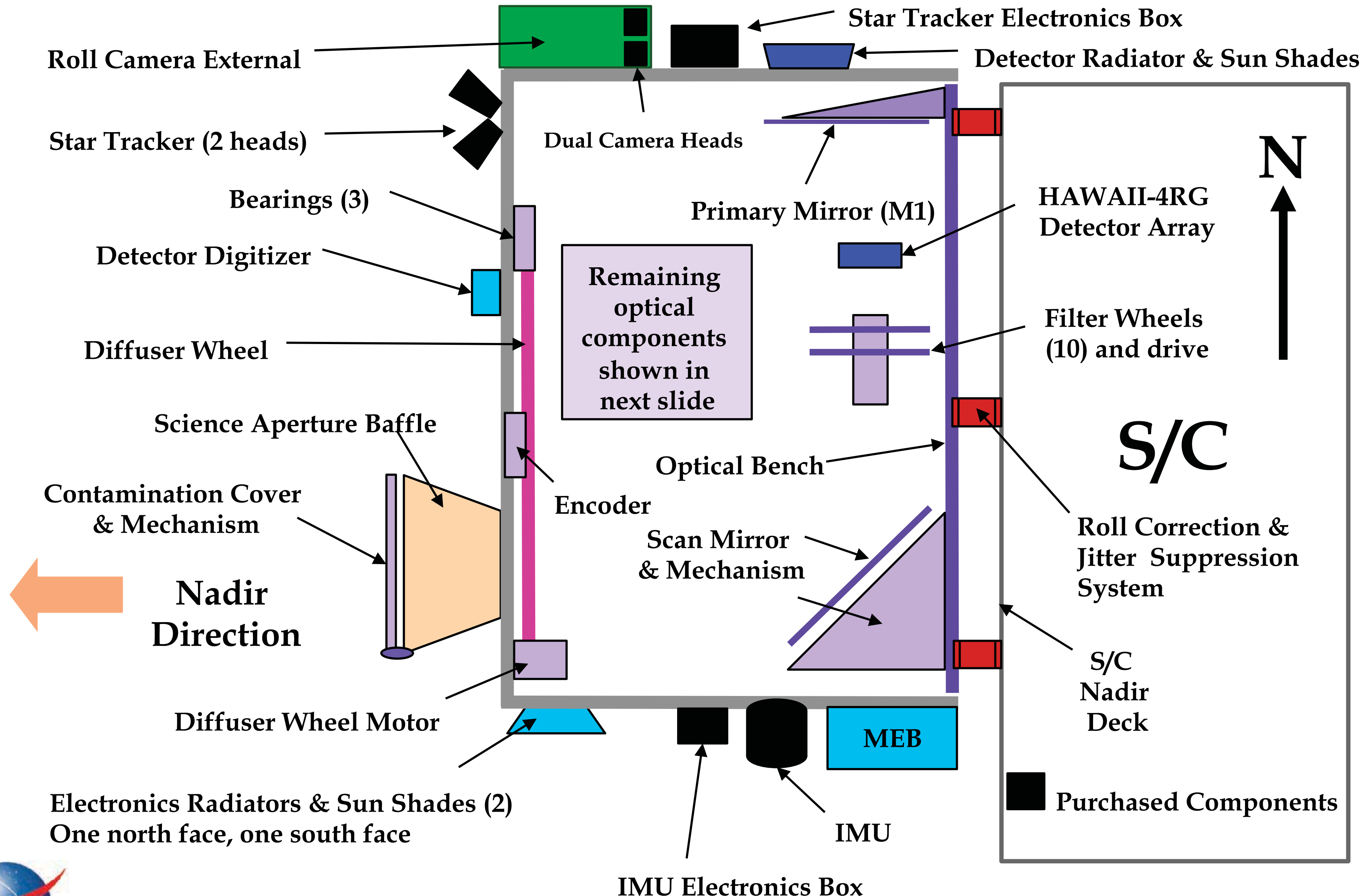
- **Pointing Line-of-Site (LOS) Error (as % of nadir pixel) Requirements:**
  - Pointing Knowledge LOS: <50% Threshold & **≤10% Baseline**
  - Pointing Accuracy LOS: <100% Threshold & **≤25% Baseline**
  - Pointing Stability LOS: <50% Threshold & **≤10% Baseline**
- **The instrument needs roll knowledge or active compensation: The roll during operation is expected to be up to ±0.1deg**
- **The instrument needs a vibration suppression system (at S/C to instrument interface)**
  - Spacecraft jitter is expected to exceed what can be tolerated.

COEDI Total Instrument Rack-up

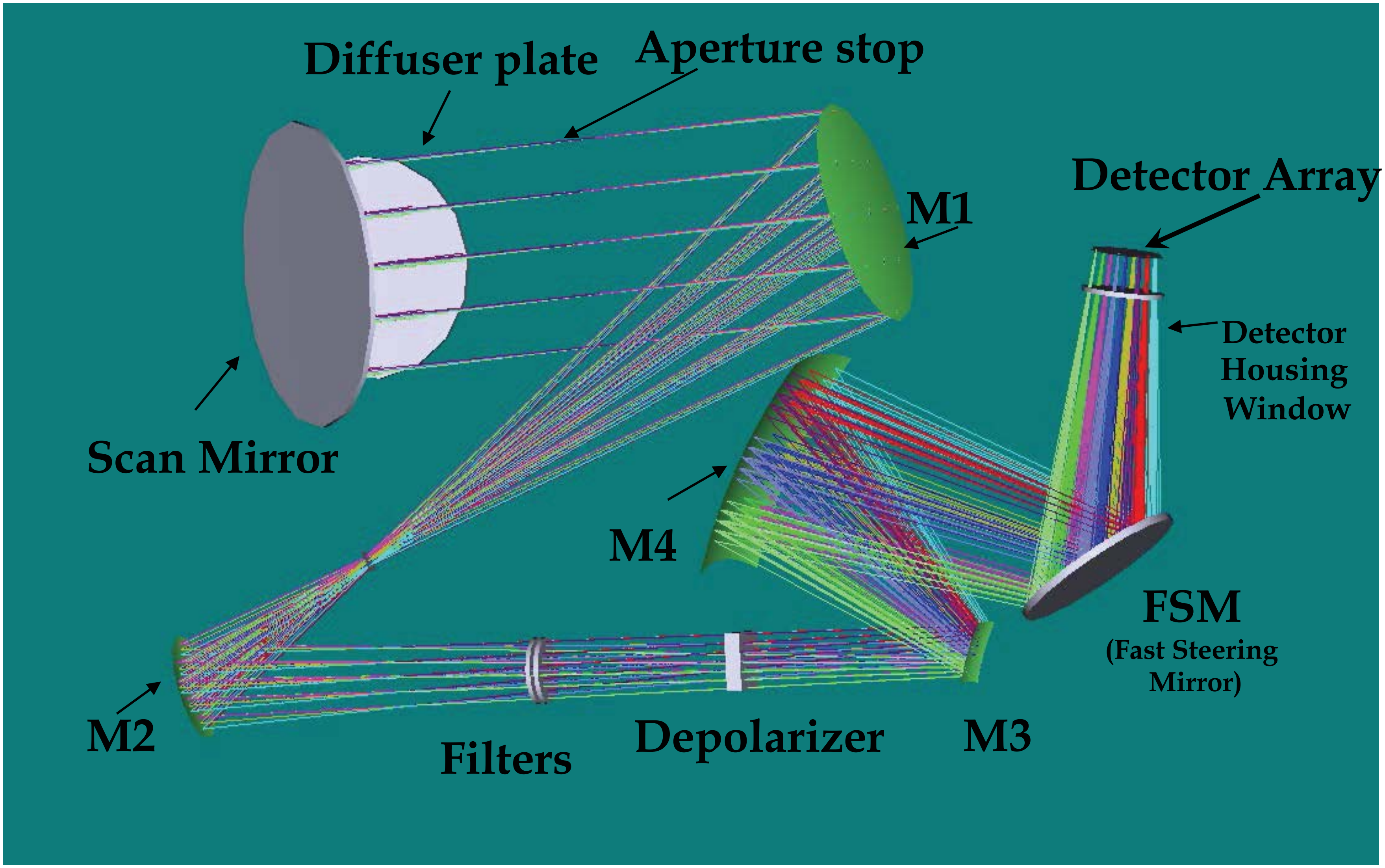
(no contingency included)

COEDI	Total Mass	Total Operating Power (Effective Average)	Total Data Rate
COEDI Science Aperture Baffle Diffuser Select Assembly Scan Mirror Assembly Telescope Assembly UV/VIS Spectrometers VIS/NIR Spectrometers SWIR Spectrometers Instrument Structure UV/VIS/NIR Digitizer Boxes SWIR Digitizer Boxes uASC + Electronics Box IMU + Electronics Box COEDI Main Electronics Box Harness Thermal Subsystem	215.5 Kg COEDI Approximate Overall Dimensions 1470x1663x1107 mm^3	192 W daily avg (220 W 17.5 hrs, 116W 5.5 hrs)	3.2 Tbits per 24hrs

FR Block Diagram

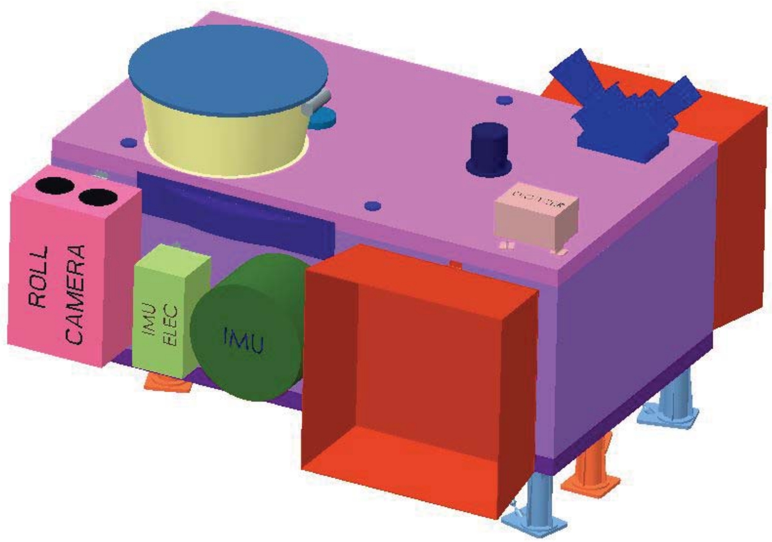


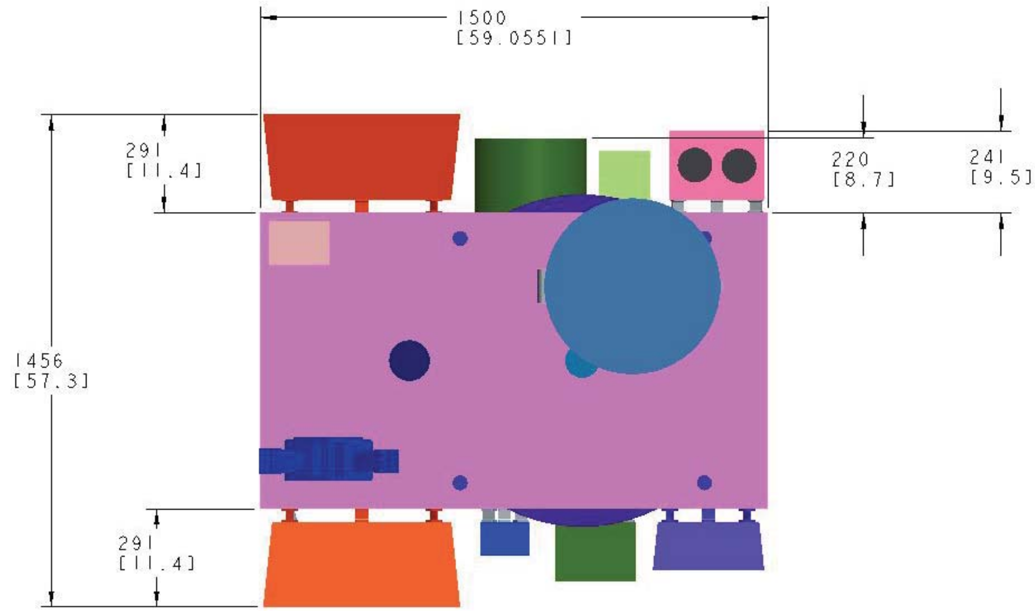
Baseline Optical Design

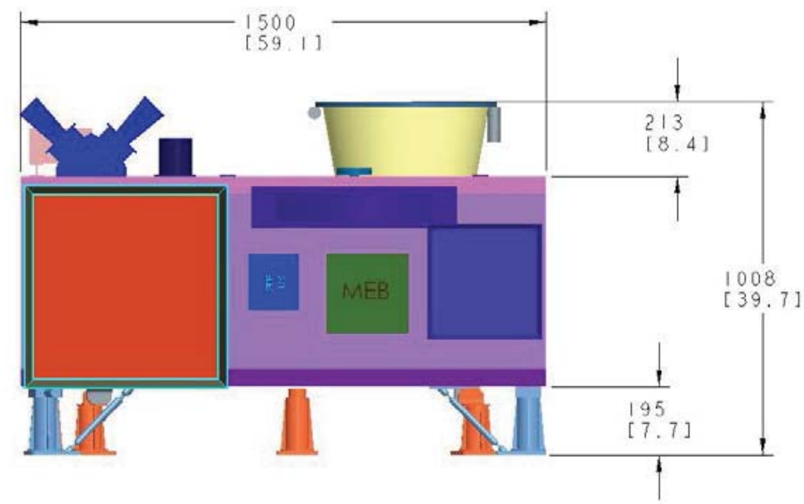


Filter Radiometer Mechanical Configuration*

Integrated Design Capability / Instrument Design Laboratory







* Courtesy of the mechanical team

IDL Study Objectives

- **Create a detailed instrument point design that meets the science objectives.**
- **Generate high fidelity cost estimates for various GEO-CAPE ocean color sensor capability trades to inform HQ and the GEO-CAPE team.**
  - *We need to generate credible bounds on instrument costs to demonstrate to HQ that the mission is viable financially (as well as technologically).*
  - Trades address spatial resolution, spectral resolution, multi- vs hyperspectral and SWIR band capabilities
  - A few optical design concepts will be examined to better constrain the costs for different instrument types (**multi-spectral filter radiometer**, hyper-spectral multi-slit and wide-angle spectrometers, etc.).
- **July 21-29 IDL Study focused on the wide-angle spectrometer design.**
- **Aug. 6-12 IDL study will develop the multi-spectral filter radiometer.**

Study Parameters

- **Class C Mission**
  - Selective electronics redundancy if there is significant improvement in reliability. None found.
  - Complete thermal subsystem redundancy.
- **3 year design life (5-yr goal)**
- **Geostationary orbit at 95W**
  - 35,786km orbit; 0-degree inclination
- **Launch Dec. 2024**
- **Hosted payload on commercial satellite; nadir view deck location (see information provided for COEDI – Aug. 2012 study)**
- **Class B Electronics components**
- **Assume host pointing performance**
  - We designed the instrument to meet the pointing and stability requirements without any additional expense to improve the spacecraft performance.
- **Labor costs – assume out-of-house build**
- **Select lower cost options where possible while maintaining performance.**

Sensor Trade Space for GEO-CAPE IDL Studies

GEO-CAPE Ocean Sensor Requirement	Filter Radiometer	Wide-Angle Spectrometer	Roll Instrument
Spatial GSD at Nadir	O = 300 m [3] B = 250 m	D = 500 m [3] T = 375 m (IDL baseline) B = 250 m (TBD)	TBD
Spectral range[1] T = 340-1050 nm	Multi-spectral[2] 16 or more bands	Hyper-spectral	1 band
SWIR Bands D = 1640 nm T = 1245, 1640 nm B = 1245, 1640, 2135nm	D = 1640 nm	1 (D), 2 (T) or 3 (B) bands [4]	none
UV/Vis/NIR Spectral Sampling/Resolution	D = 10 nm	T = 2.5/5 nm [3] ; B = 0.4/0.8 nm; O = 2/5 nm, but 0.4/0.8 nm for 400-450nm [3]	wide

T = Threshold requirements from STM (but not including the NO_2 requirements)
B = Baseline Requirements from STM (includes the NO_2 requirements)
O = Between Threshold and Baseline   D = Descope
[1] SNR >1000 for UV-Vis (at 10nm FWHM) – see table
[2] Multispectral: ~MERIS bands plus 360, 385 & 1020 nm. SWIR additional.
[3] Compute cost by scaling sensor and results from IDL study.
[4] Track costs for additional SWIR bands within MEL without impacting instrument design.

Configuration Modifications for Delta Designs

- **Nadir GSD**
  - IDL Baseline: 250m
  - Deltas:
    - 375m (by scaling optical design - “pre-costing” approach)
    - 500m (by scaling optical design - “pre-costing” approach)

- **Spectral Resolution UV-VIS and VIS-IR**
  - IDL Baseline: 5nm bandwidth most bands, 40nm for the four longest wavelengths
    - Details are in the radiometry presentation
  - Deltas: no change in resolution was to be considered
    - During the study, the baseline number of filters was increased from 16 to 50 and the typical bandwidth reduced to 5nm from 10nm

- **SWIR Bands**
  - IDL Baseline: Two SWIR bands at 1245nm and 1640nm
  - Descope: Remove the entire SWIR channel by replacing the MCT detector material with silicon.
    - MCT with the substrate removed has reasonable quantum efficiency (QE) down to 300nm.
    - Two filter wavelengths would be changed

Other Major Components

- **2D camera for roll detection**
  - Two applications
    - Data to actuator (at S/C to instrument interface), which moves the entire instrument to correct for roll
    - Provide information for geo-location reconstruction on the ground
  - Specifications
    - Same # pixels as science instrument (2k) or preferably more
    - Higher spatial resolution than the science instrument (possibly by 10x) to detect roll motion by viewing a coastline (contrast of bright land next to dark ocean).
    - Detector read at ~100Hz

- **Instrument IMU and 2 head star tracker for pointing knowledge.**

- **FSM (fast-steering mirror) to correct for jitter motion detected by the IMU (Inertial Measurement Unit).**

Performance Goals

- **Signal-to-Noise Ratio (SNR) at Ltyp (70˚ SZA) - see STM & SNR table**
  - ≥1000:1 for 10 nm FWHM (350-800 nm) (Threshold) – Designed to Meet
  - Aggregate SWIR bands up to 2x2 GSD pixels to meet SNR (Threshold) - Meets
  - Aggregate NO_2 bands up to 3x3 GSD pixels to meet 500:1 SNR (Threshold) not met with baseline filter bandwidths
- **Scanning area per unit time:**
  - Baseline: ≥50,000 km^2/min, this rate permits ≥6 scans of U.S. coastal waters including Laurentian Great Lakes per day.
- **Field of Regard: Full disk: 20.8° E-W and 19° N-S imaging capability from nadir for Lunar & Solar Calibrations – Meets by Design**
- **Non-saturating detector array(s) at Lmax – Meets by Design**
- **On-board Calibration: Lunar - minimum monthly; Solar – daily - Meets**
- **Polarization Sensitivity: Requirement <2%, goal** <1.0% – Requires additional analysis, including consultation with coating vendors, **should be able to show Meets by Design**
- **Relative Radiometric Precision: ≤1% through mission lifetime - Meets**
- **Pointing Line-of-Site (LOS) Error (as a percentage of 1 nadir pixel) - Meets**
  - **Measured by roll camera, closed loop control with actuators and combined with vibration suppression system**
  - Pointing Knowledge LOS: <50% Threshold & <10% of 1 nadir pixel Baseline
  - Pointing Accuracy LOS: <100% Threshold & <25% of 1 nadir pixel Baseline
  - Pointing Stability LOS: <50% Threshold & <10% of 1 nadir pixel Baseline
  - Geo-location Reconstruction: <100% Threshold & <10% of 1 nadir pixel Baseline

Original Baseline SNR Requirements

		(SZA = 70ϒ)				
λo - nm	Δλ - nm	W/m^2-Δλum-ster		Req'd		
Bands	FWHM	Ltyp	Lmax	SNR_{req}	Required Minimum Set of Multi-Spectral Bands[1]	NOTES
350	15	46.90	166.2	1,000		
360	10	45.40	175.6	1,000	Yes	
385	10	38.40	177.9	1,000	Yes	
412	10	49.50	281.1	1,000	Yes	
~~425^~~	~~0.8~~	~~48.20~~	~~277.0~~	~~500~~		For estimating SNR for NO2 retrievals
443	10	45.00	271.3	1,000	Yes	
460	10	41.90	266.0	1,000		
475	10	38.20	261.3	1,000		
490	10	34.90	256.6	1,000	Yes	
510	10	29.00	250.3	1,000	Yes	
532	10	23.30	243.4	1,000		
555	10	18.50	224.9	1,000	Yes	
583	10	15.30	227.4	1,000		
617	10	12.20	216.7	1,000	Yes	
640	10	10.50	209.5	1,000	Trade Study swap	
655	10	9.57	204.7	1,000		
665	10	9.17	201.6	1,000	Yes	
678	10	8.66	197.5	1,000	Yes	
710	10	6.95	187.5	1,000	Yes	
748	10	5.60	175.5	600	Yes	
765	40	5.25	170.2	600	Yes	
820	15	3.93	152.9	600		
865	40	2.77	138.8	600	Yes	
1020	40	1.48	109.1	450	Yes	
1245*	20	0.582	56.10	250		
1640*	40	0.178	19.70	180	Trade Study swap	
2135*	50	0.040	5.35	100		

[1] Additional bands between 360-1020nm desirable; SNR should not be an issue for the additional bands.

^ Pixels can be aggregated up to 3x3 to achieve required SNR of 500:1 for atmospheric NO2 retrievals

* Pixels can be aggregated up to 2x2 to achieve required SNR

Operational Concept

- **Calibration**
  - Dark calibration - performed at start and end of the day
  - Solar and lunar calibrations as needed (daily to weekly solar; lunar as frequently as lunar views permit)
    - Scan as needed to illuminate all detector pixels
    - Mechanisms: wheel with diffusers for solar calibrations
      - Would like to keep costs of solar cal. capability within MEL distinct for possible de-scoping.
- **Science**
  - Step and Stare with scan mirror
    - Continuous science scans of the Earth for ~16 hours/day
    - Scan U.S. coastal waters (500km wide scenes) every 1-3 hours.
    - Scan non-U.S. coastal and open ocean waters as time permits.
    - Integration time per iFOV depends on minimum L_{typ} within iFOV (ranging from 0.5 to >2 seconds).
    - Survey and Targeted modes (higher frequency sampling)
  - The list of targets are predefined on the ground and uploaded to the instrument on a weekly basis. The load can be updated daily if needed to take into account cloud cover. For each target, ground uploads: Target starting location, Length of time to integrate at each step (stare), Length of time to integrate at each wavelength, Total length of time to observe the target.
- **Repeat**

Instrument Modes

- **Launch**
  - Instrument Off, Survival Heaters On
- **Standby/Safe - Enter this mode upon power up or a ground command**
  - Diffuser Wheel is in the closed position and off; Scan Mirror and FSM are powered off
  - MEB, Star tracker, IRU, Roll Camera, Detectors and Digitizers are all left on to avoid temperature cycling the electronics.
  - Operational temperatures are maintained; Housekeeping data collected.
  - Diagnostics and software updates are performed in this mode.
- **Science**
  - Survey and Targeted (high frequency sampling)
  - The same operation for both Survey and Targeted: step and Stare
  - Duration about 16 hours/day
  - The list of targets are predefined on the ground and uploaded to the instrument on a weekly basis. The load can be updated daily if needed to take into account cloud issues. For each target, ground uploads: Target starting location, Length of time to integrate at each step (stare), Total length of time to observe the target
  - Enter Science Mode by either ground or stored command.
    - Typically stored command since the start time will be in the weekly upload.
- **Calibration**
  - Cal-Dark – Performed regularly at the start and end of the day
  - Cal-Moon and Cal-Sun – as needed
    - Commanded from the ground

Instrument Calibration

- **Cal-Moon**
  - Duration ~5 min; radiometric calibration, performed when moon in the FOR; 3-5 times per month; Scan North/South and East/West for averaging; Performed as needed; Observation sequence and integration time are commanded from the ground
- **Cal-Sun**
  - Duration ~20 min; performed when sun in the FOR (at night time); Initially performed daily but less frequent (weekly) later on; Observation sequence and integration time are commanded from the ground
  - Cal-Sun Types:
    - Standard Solar Diffuser used daily at first, then weekly.
    - Degradation Monitoring with second standard Solar Diffuser, done about once per month.
- **Cal-Star Tracker**
  - Duration ~20 min; Line-of-Sight (LOS) calibration to eliminate bias error; View dark star field (no sunlight or moon); Continuous at low rate such as once per hour
- **Cal-Dark**
  - Duration ~5 to 30min; Dark counts for detectors; Performed during the night to maximize science data collection; Planned twice a day (at the start and end of the day)

Mission Operations Concept

Mode	Function	Frequency	Duration	Mechanism Configuration		
				Diffuser Wheel Mechanism	Scan Mirror Mechanism	FSM
Launch				Closed, Off & Launch Locked	Off & Launch Locked	Off
Standby	Health & Safety, FSW upload, Diagnostic, overnight	Daily	~7 Hours/day	Closed; off	Off	Off
Science	Survey & Targeted	Daily	16 Hours/day	Clear	Move & Stare	On
Cal - Moon	Lunar radiometric cal	When available, 3 to 5/Month	~5 min	Clear	Move & Stare	On
Cal - Sun	Solar radiometric cal	When available, Daily - Weekly	~5 min	Solar Diffuser or Rare Earth Doped	Move & Stare	On
Cal - Star Tracker	Calibrate instrument LOS wrt attitude hardware	Once per hour	Continuously	Any	Move & Stare	On
Cal - Dark	Measure detector dark current and bias	2 x Daily	~5 min	Closed	N/A	N/A

Systems Presentation Part II

GEO CAPE Filter Radiometer (FR)

~ Concept Presentations ~

Optics

Mark Wilson/Code 551

Aug 12, 2014

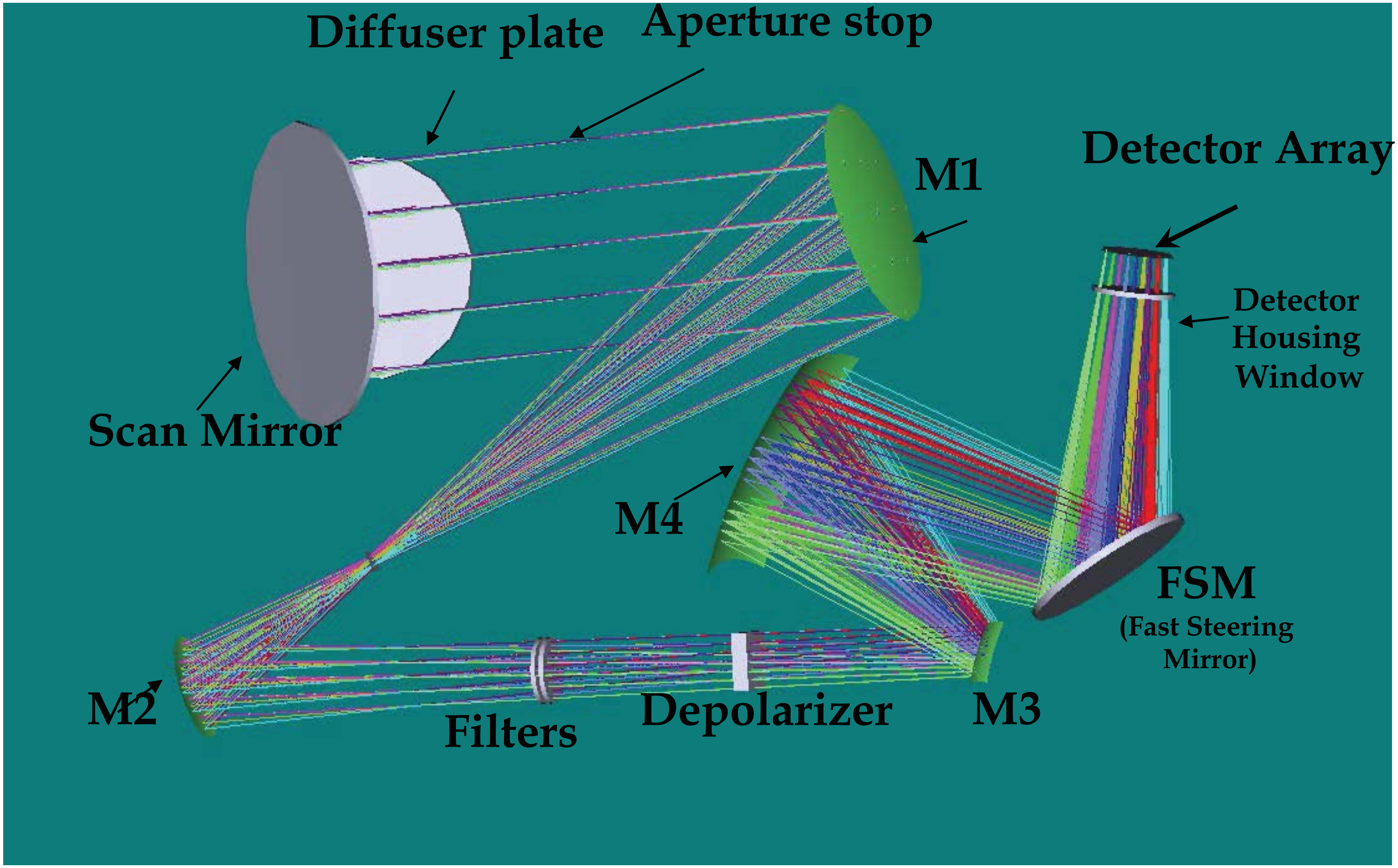
System Requirements

- **Aperture = 250 mm diameter**
- **Geosynchronous orbit (35786 km)**
- **Wavelength range from 345 nm to 2155 nm**
- **Ground footprint = 250 m diameter**
- **The field of view will be imaged on a 4k x 4k detector array of 15um pixels.**
    - Each ground pixel is spread over 2 x 2 detector pixels so the instantaneous field of view (IFOV) is 2048 X 2048 ground pixels
- **Scan mirror used for scanning Earth**
    - Angular range of motion is +/-5.1 degrees along both axes
- **Accommodate up to 50 optical filters**

Derived Optical Requirements

- **Full field of view: 0.82 degree square**
- **F/17 at focal plane**
- **Image quality: 80% ensquared energy in a science pixel throughout the field of view**
- **Polarization sensitivity <2% (goal of 1%) through entire wavelength range**

Baseline Optical Design



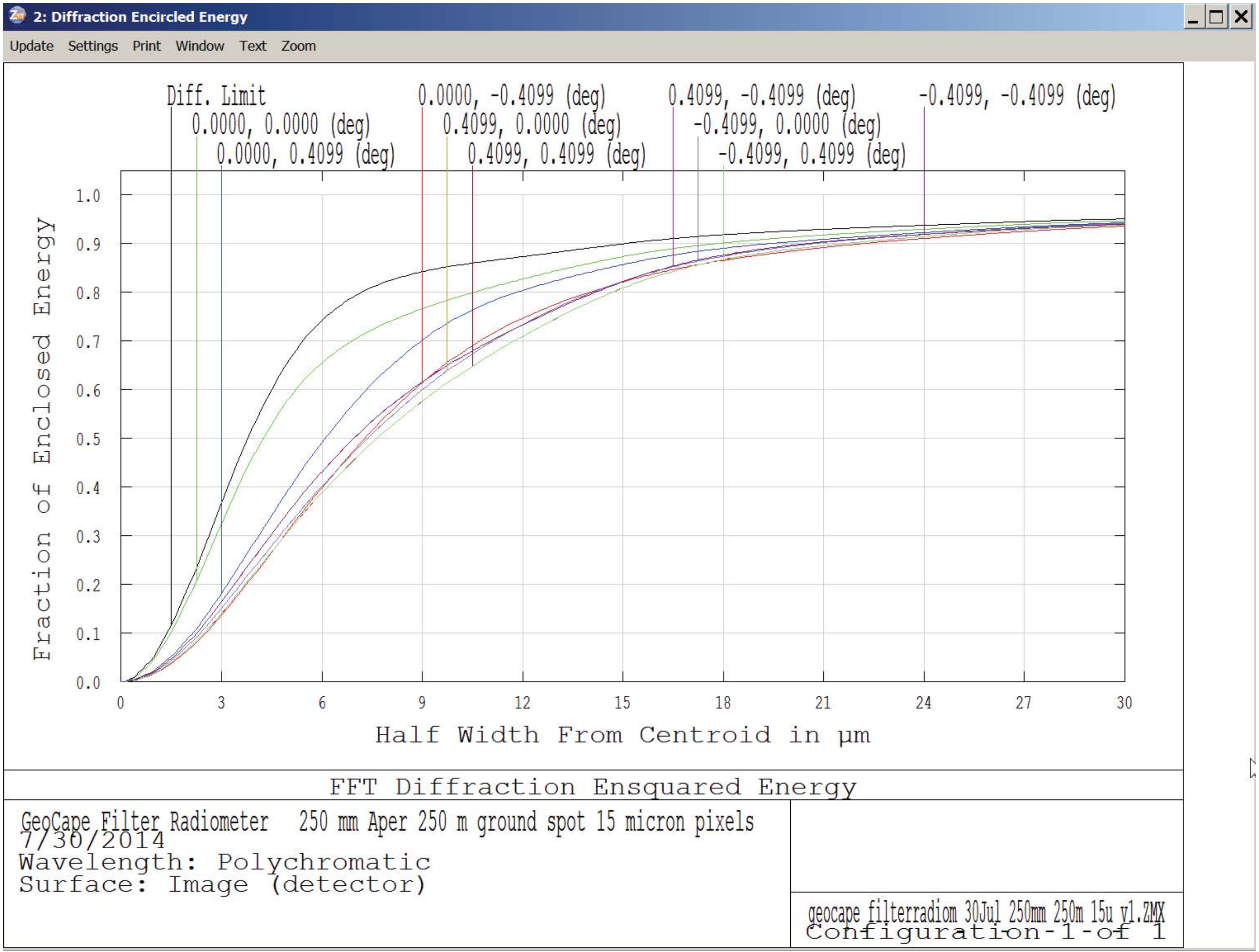
Optical Element list

ELEMENT	FIGURE	SHAPE	SIZE (FULL, MM)	MATERIAL
DIFFUSER PLATE (thickness not optimized)	FLAT	CIRCULAR	350 X 10	FUSED SILICA
SCAN MIRROR	FLAT	OVAL	500 X 330	ULE
M1 MIRROR	OFF AXIS HYPERBOLA	CIRCULAR	270	ULE
M2 MIRROR	OFF AXIS ELLIPSE	CIRCULAR	110	ULE
M3 MIRROR	OFF AXIS ELLIPSE	RECTANGLE	66 X 66	ULE
M4 MIRROR	6TH ORDER ASPHERE	RECTANGLE	236 X 200	ULE
FAST STEERING MIRROR	FLAT	RECTANGLE	140 X 172	ULE
OPTICAL FILTERS	FLAT	CIRCULAR	80 X 6	FUSED SILICA
DEPOLARIZER	FLAT	RECTANGLE	80 X 80	QUARTZ
DETECTOR WINDOW	FLAT	RECTANGLE	70 X 70 X 6	SAPPHIRE
ROLL CAMERA LENS 1	SPHERE	CIRCULAR	92	BALKN3
ROLL CAMERA LENS 2	SPHERE	CIRCULAR	88	F4
ROLL CAMERA LENS 3	SPHERE	CIRCULAR	60	BK7
ROLL CAMERA LENS 4	SPHERE	CIRCULAR	58	F2
ROLL CAMERA LENS 5	SPHERE	CIRCULAR	42	F2
ROLL CAMERA OPTICAL FILTER	FLAT	CIRCULAR	92	FUSED SILICA

Mass of optical elements

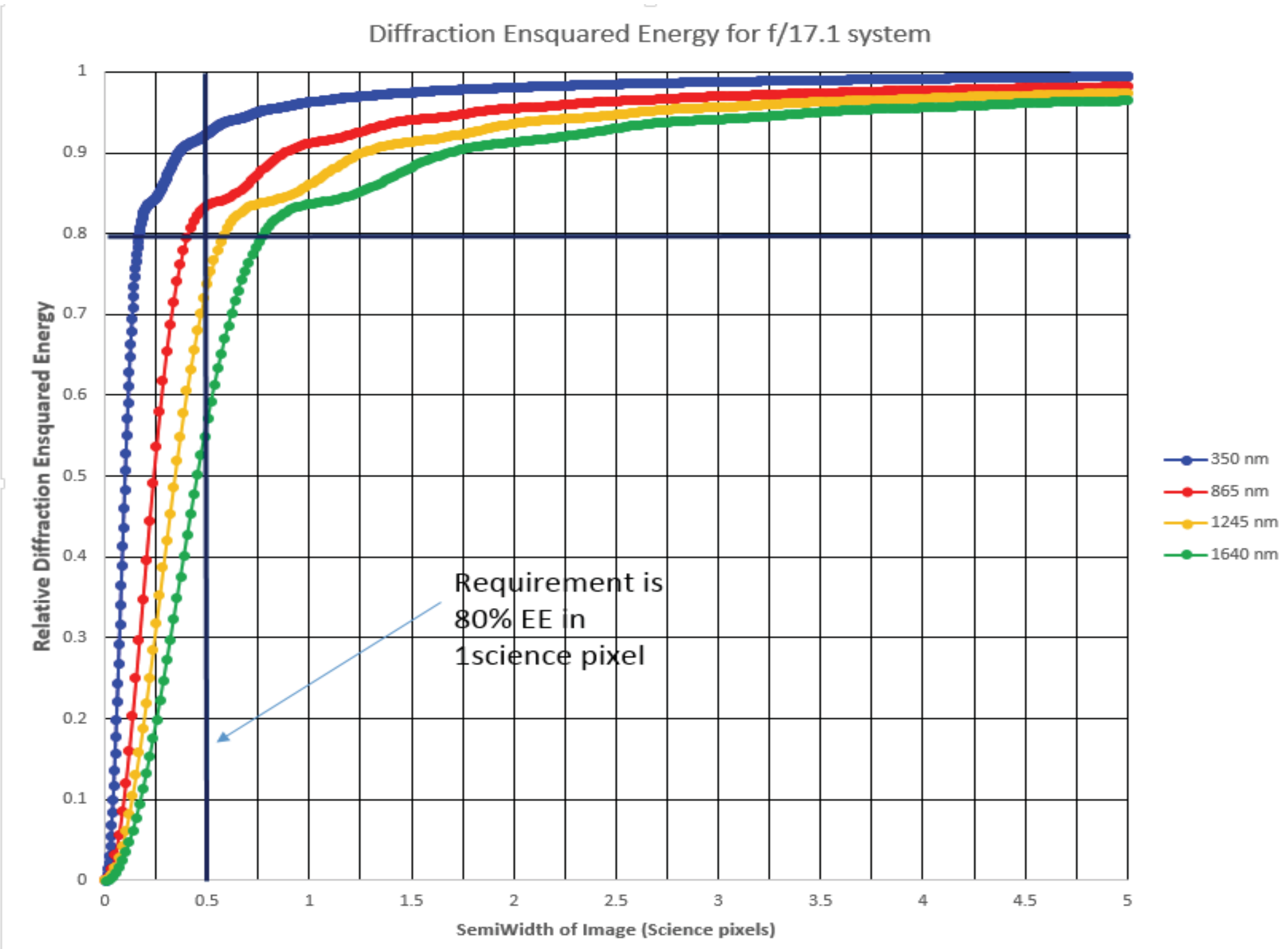
OPTICAL ELEMENT	Material	Mass (kg)	Lightweighting factor
Scan Mirror	ULE	3.637	50%
M1	ULE	1.265	
M2	ULE	0.210	
M3	ULE	0.096	
M4	ULE	0.782	
Fast Steering Mirror	ULE	0.266	
Filters (50)	Fused Silica	3.318	
Depolarizer	Quartz	0.282	
Window	Sapphire	0.117	
Diffuser Plates (2)	Fused Silica	4.253	
Roll Camera Lens 1 (2)	BALKN3	0.369	
Roll Camera Lens 2 (2)	F4	0.252	
Roll Camera Lens 3 (2)	BK7	0.054	
Roll Camera Lens 4 (2)	F2	0.140	
Roll Camera Lens 5 (2)	F2	0.045	
Optical Filter (2)	Fused Silica	0.175	
		15.086	TOTAL

Optical Performance



Optical Performance, cont'd

- **Diffraction limits performance in SWIR channels**

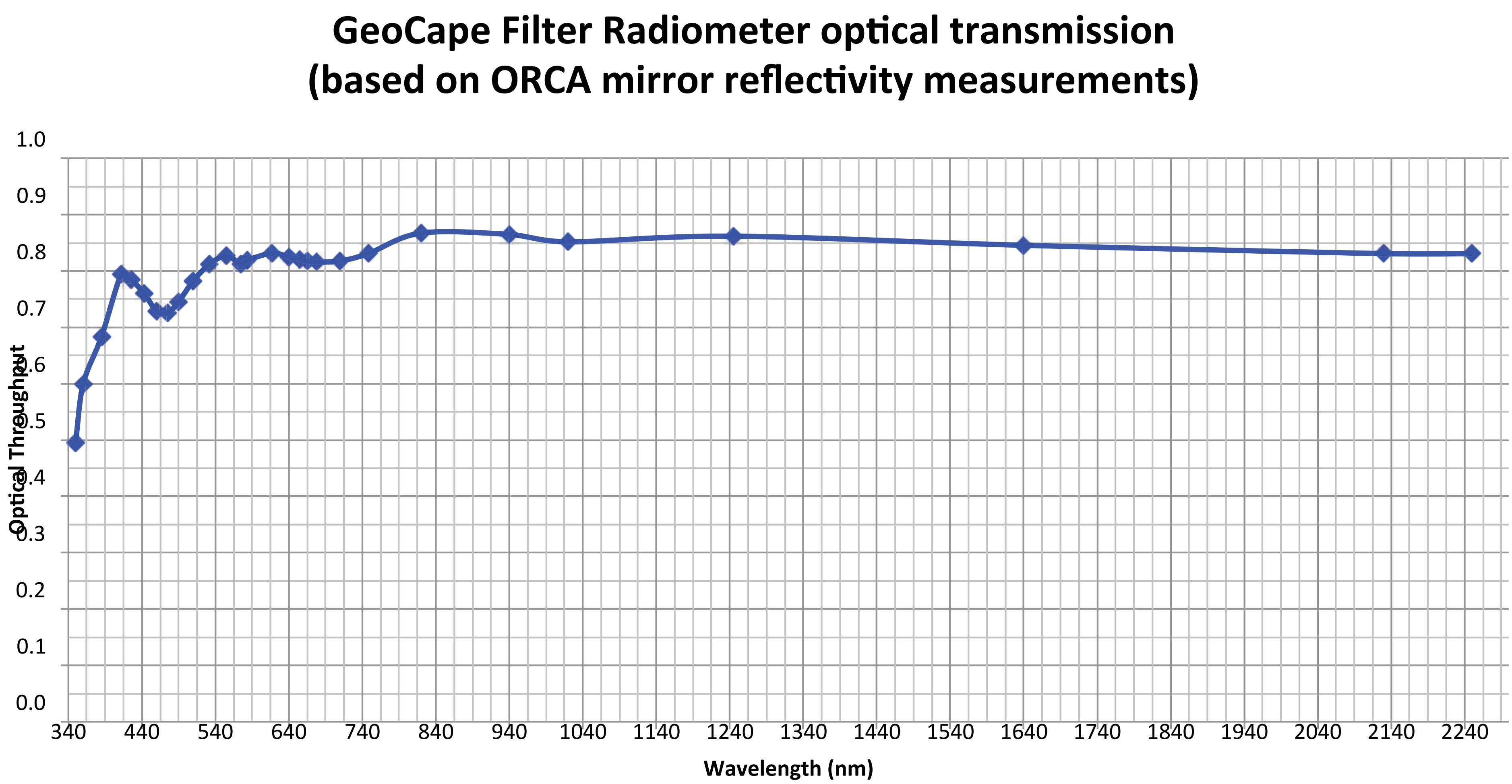


Optical Transmission

- Based on silver coating developed for ORCA - >95% reflectivity at 350 nm (coating prescription proprietary to 1 company)
- Alternative is silver coating flown on Kepler mission
- AlMgF2 coatings possible, have lower throughput in the ~700-800 nm range than silver

Optical Transmission, cont'd

Integrated Design Capability / Instrument Design Laboratory



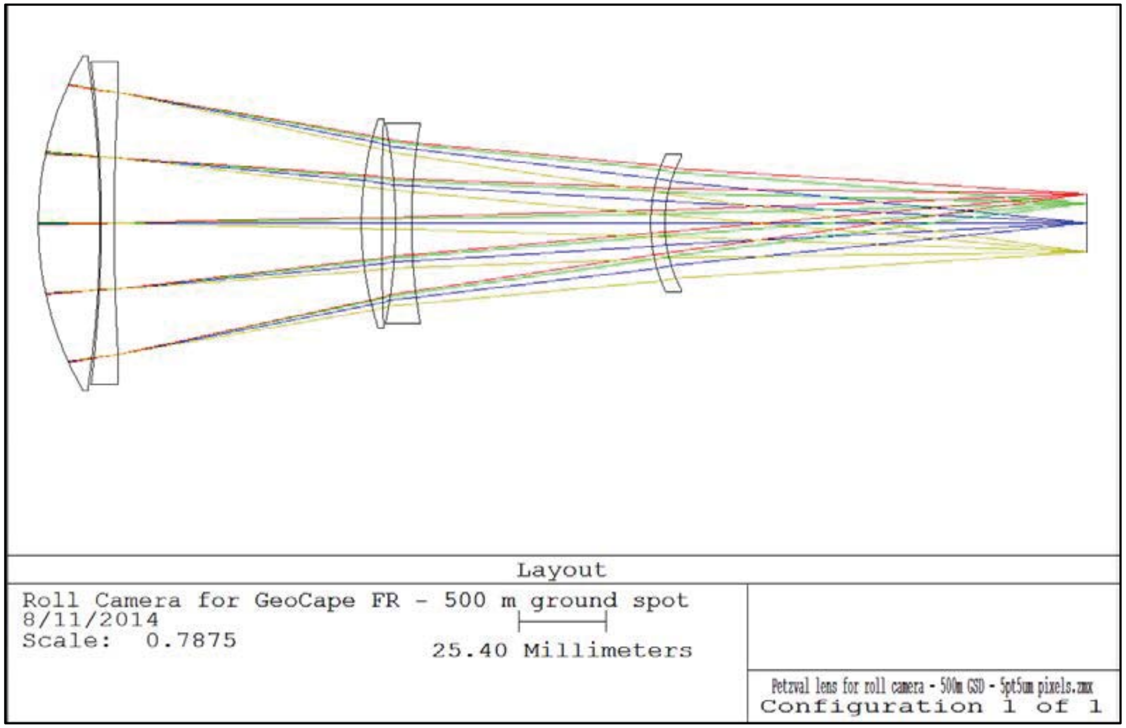
Fast Steering Mirror

- **Image motion Sensitivity* = 1 arcsec/0.121 science pixels**
  - Assumed rotation about center of front surface of FSM
  - Assumed no lightweighting of mirror

* For a 1 arcsec rotation of the FSM, the image moves by 0.121 science pixels

Roll Camera

- Focal length designed to image ground spot onto 5.5 micrometer detector pixel: EFL = 400 mm
- Scaled from WAS design by 400/525 = 0.762
- Current entrance pupil diameter = 82 mm (no radiometric analysis done for roll camera)
- Standard Schott glasses used



Comments/Concerns

- **Image quality specification (80% EE in 1 science pixel) is challenging**
  - Corner of the field of view is driver (current design leaves very little margin for fabrication and alignment errors)
- **Mirror fabrication will be expensive but within current fabrication limits**
- **5 nm bandpass filters are achievable but somewhat more expensive than many filters; sharpness of cutoff is primary cost driver.**
- **Primary contributor to polarization sensitivity is scan mirror**
  - Coating design optimized for 45 deg angle of incidence and transmissive depolarizer should reduce the impact but requires additional analysis, including consultation with coating vendor
- **Other optical designs with smaller filter sizes may be possible**
- **Still working baffle layout**
- **Current mirror coating being recommended is not flight qualified yet**
  - ORCA is planning radiation test but risk is it may not happen
  - Using Kepler silver coating will reduce throughput in 350 band to ~5%
- **For Roll camera, modifications are still needed**
  - need to reduce entrance pupil size (82 mm to 50 mm) (KEEP SAME FOCAL LENGTH)
    - Keeps overall length the same but uses smaller optics
  - Need to include bandpass filter
  - Rad hard glass materials needed

Increasing ensquared energy in 1 pixel

- **To improve ensquared energy to 90% in 1 science pixel,**
  - Change f/number to ~f/9
    - For the same aperture size (250 mm), the focal length needs to change to 2100 mm – ground spot diameter = 475 m
    - For the same (current) optical system focal length, the diameter needs to change to 477 mm
    - Airy diameter = 0.63 science pixels (84% EE)
    - Going from 85% to 90% = 0.33 pixels (ADDITIVE to Airy diameter)
    - Design/Fabrication/Alignment errors = 0.2 science pixels (RSS'd with other contributions)
  - Modify optical surface shapes to achieve diffraction limit

GEO CAPE Filter Radiometer (FR)

~ Concept Presentations ~

Mechanical Systems

Mike Clark
Bobby Nanan
Liz Matson

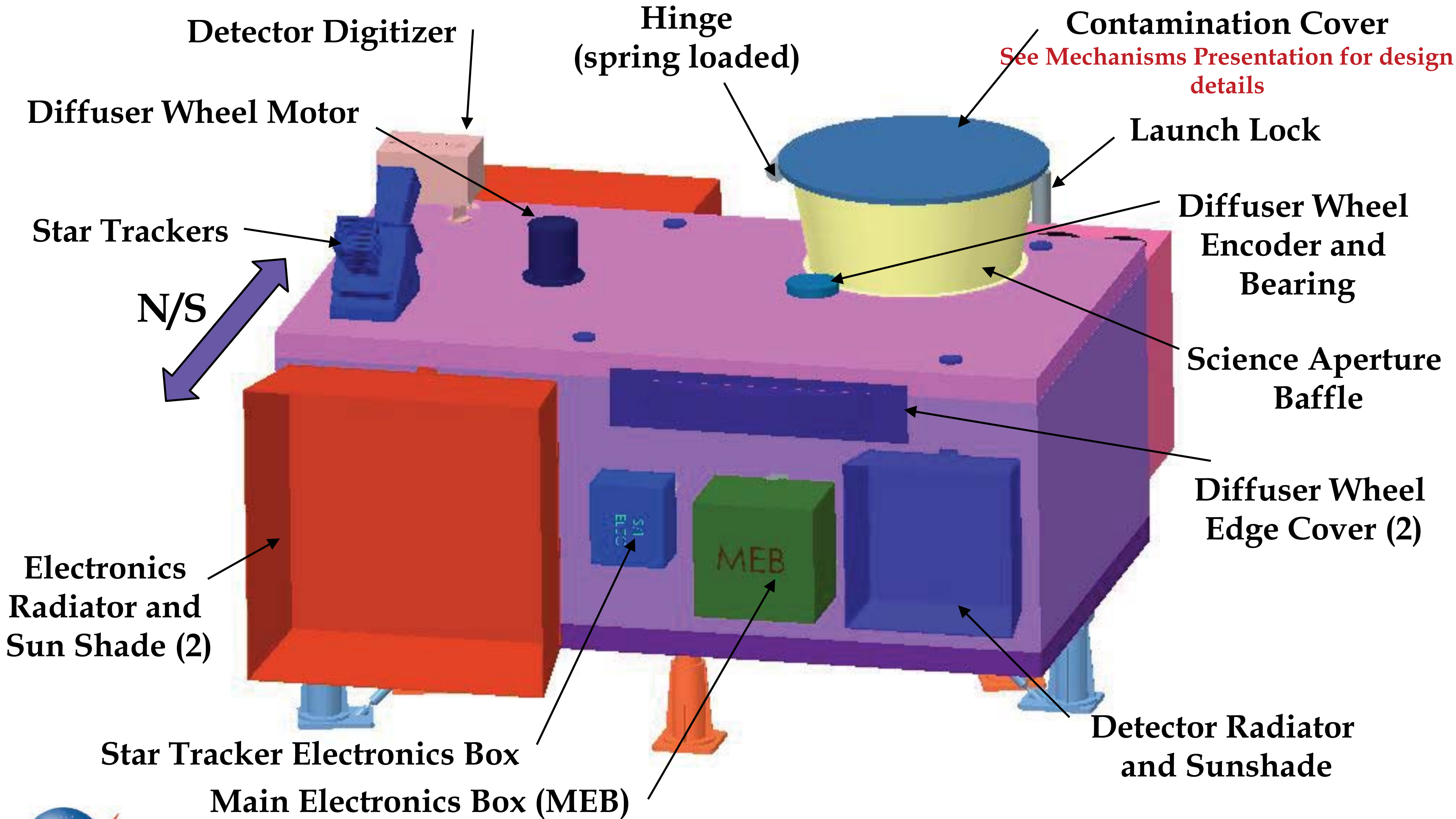
Aug 12, 2014

Requirements

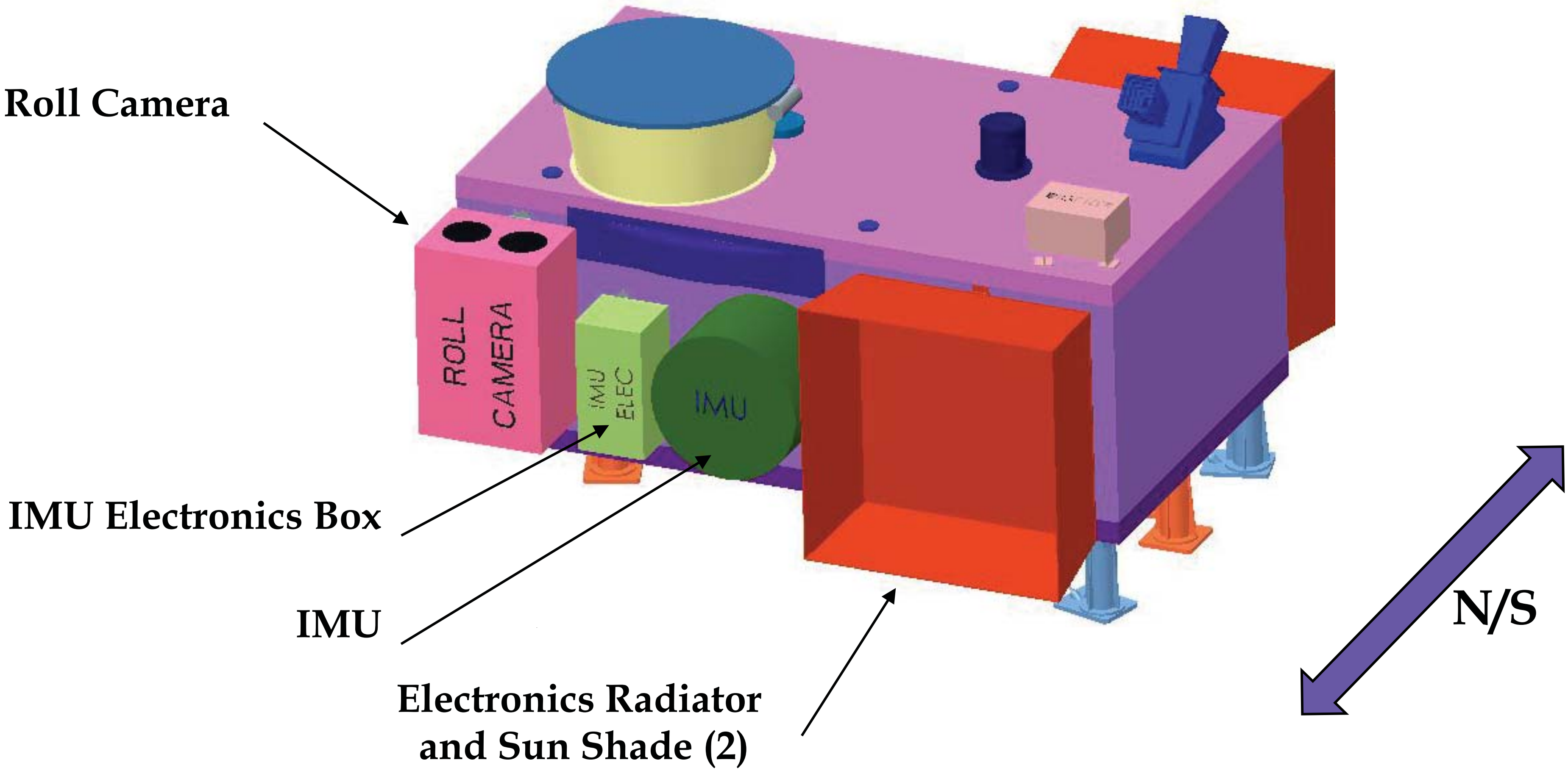
- Package instrument components including optical, electrical, and thermal, and mechanisms.
- Minimize mass and volume
- Demonstrate compatibility with “Engineering Allocations” (i.e. volume and mass)

Instrument Overview

Integrated Design Capability / Instrument Design Laboratory



Instrument Overview



Diffuser Wheel

Integrated Design Capability / Instrument Design Laboratory

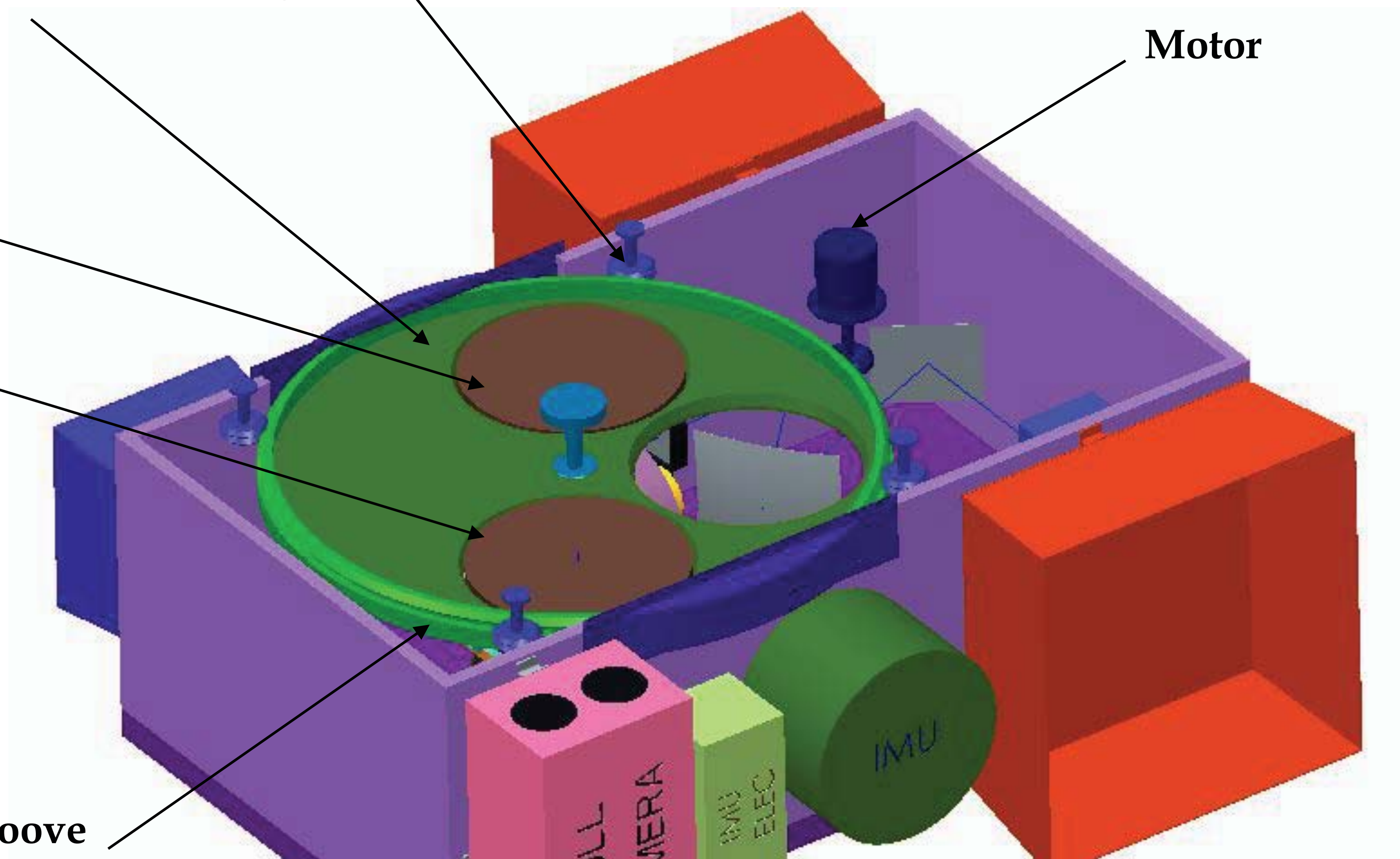
Diffuser Wheel
25 mm Alum Core
1.5 mm Alum f/s

Bearings (4)

Motor

Diffuser 1

Diffuser 2



Gear Teeth and V-groove
(on periphery of wheel)

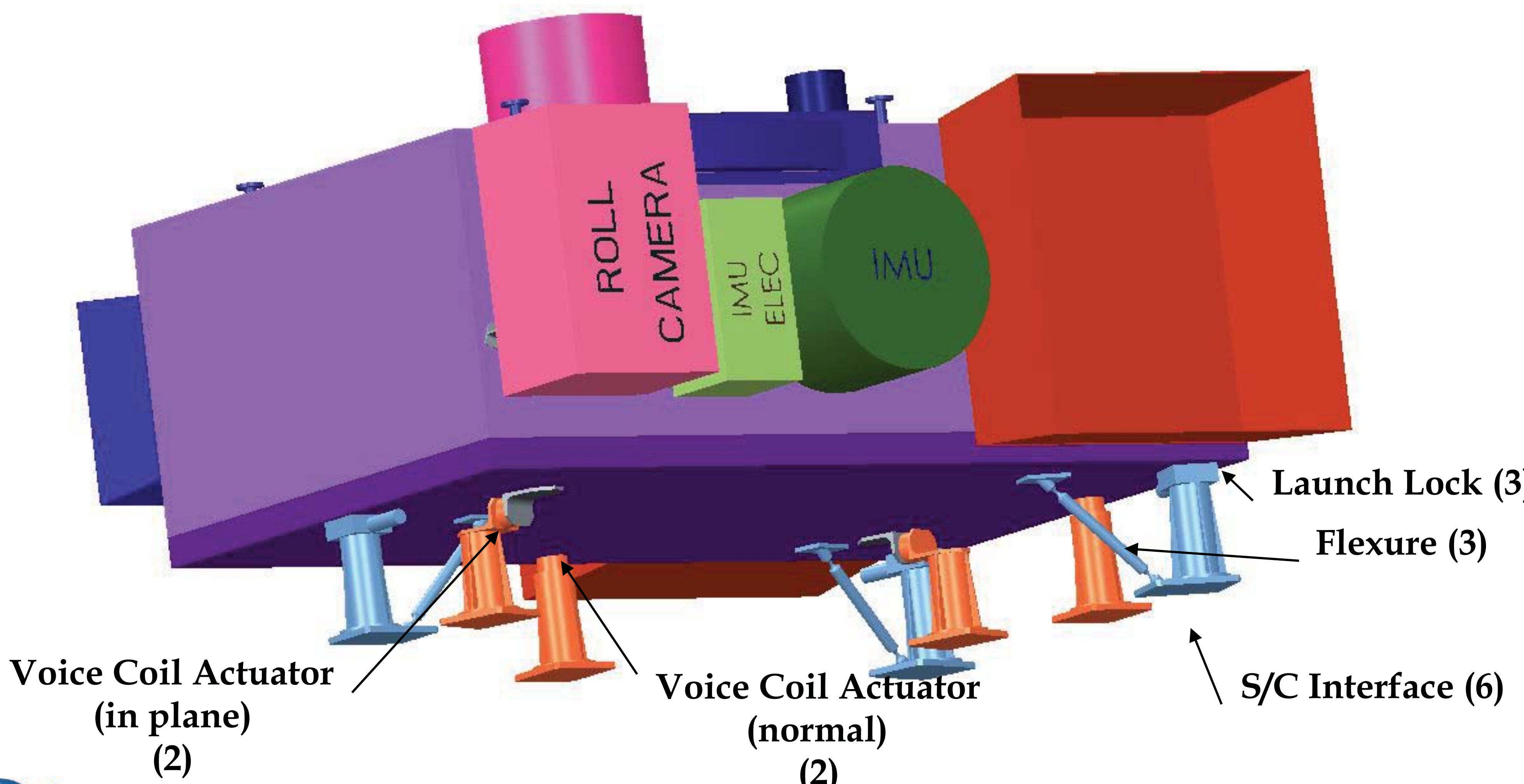
See Mechanisms Presentation for design details

S/C Interface – Roll Compensation and Jitter Suppression System

Integrated Design Capability / Instrument Design Laboratory

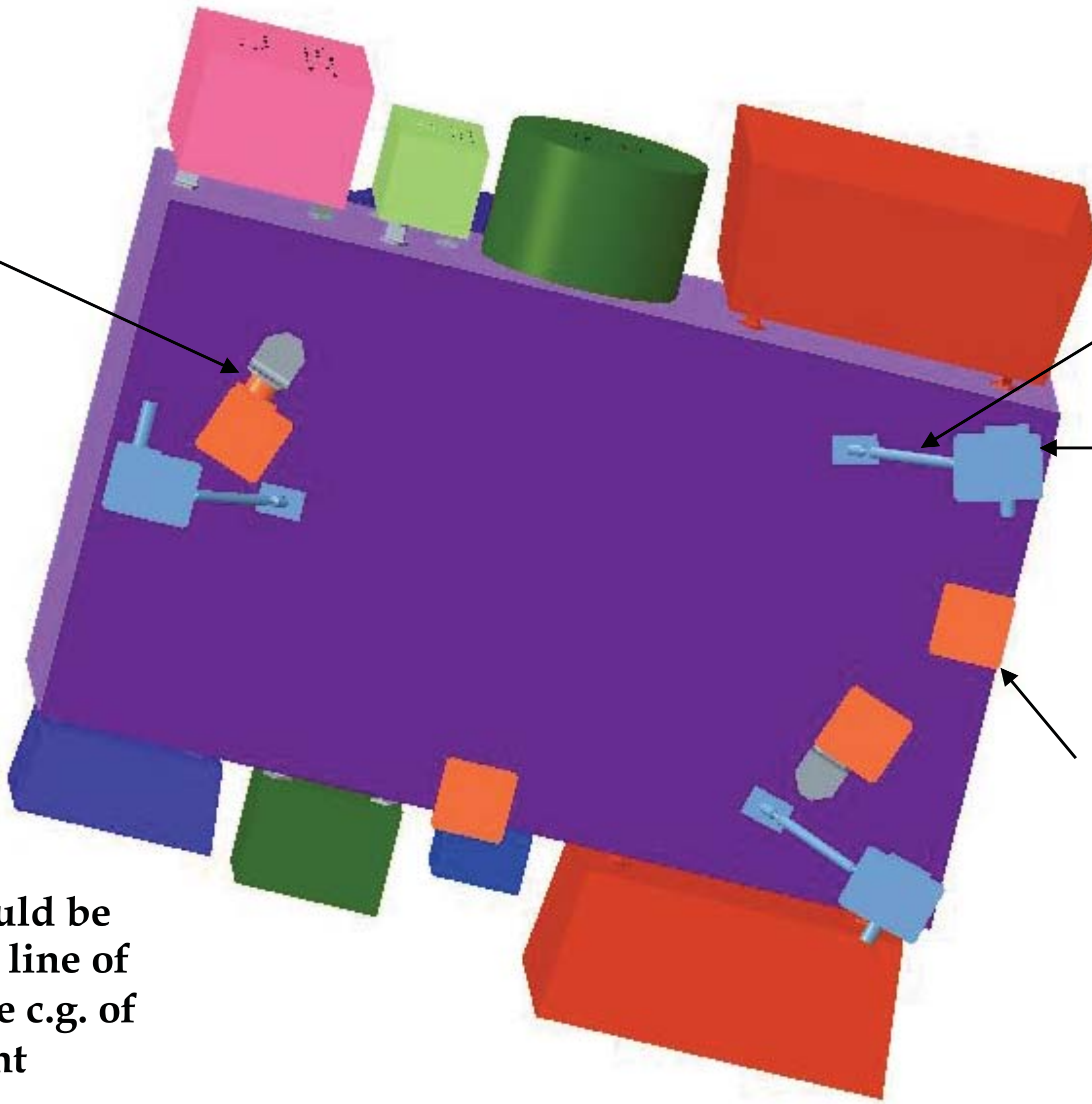
See Mechanisms Presentation for design details

Note: Flexures would be oriented so that the line of action is through the c.g. of the instrument



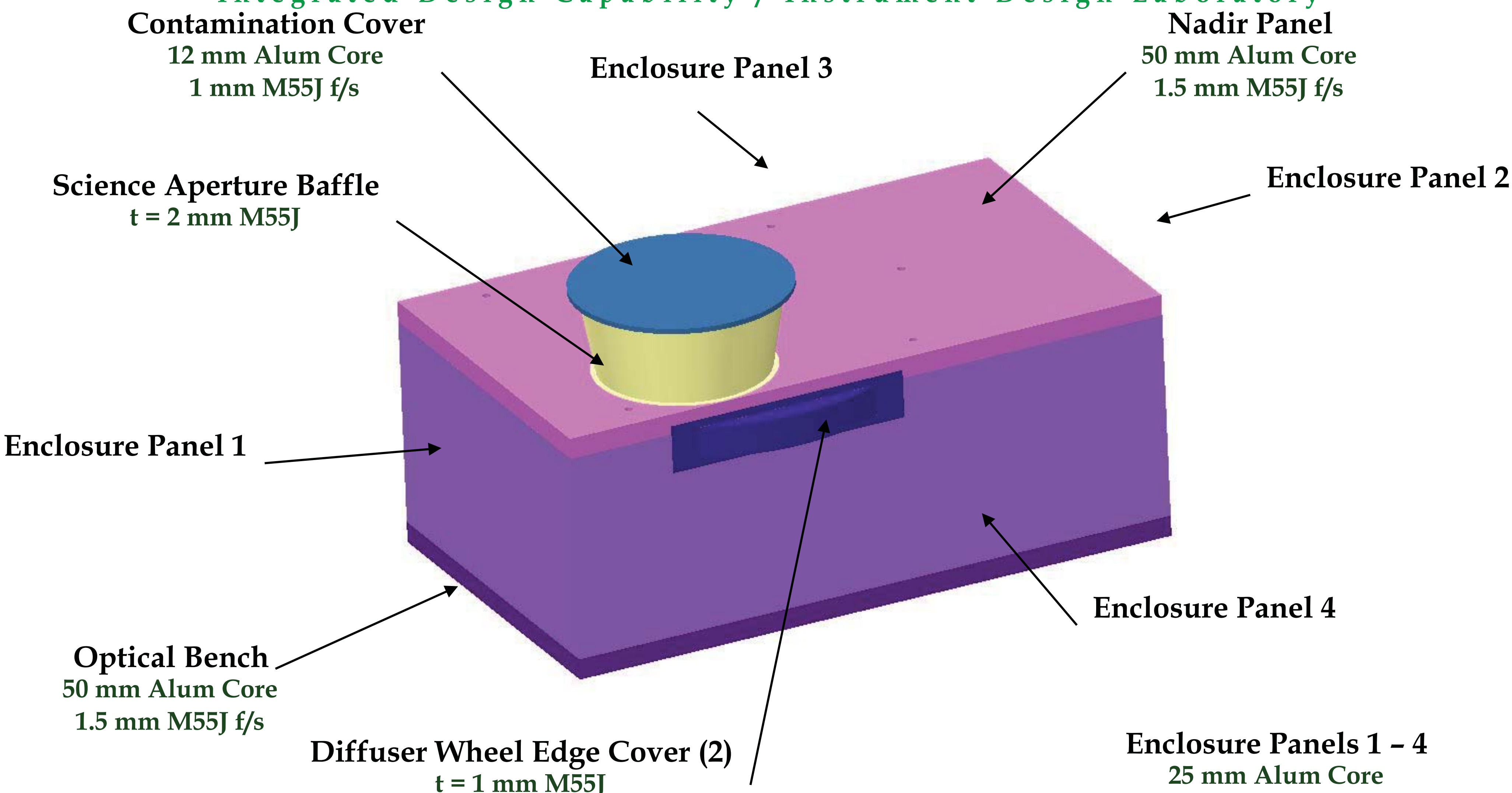
S/C Interface – Roll Compensation and Jitter Suppression System

See Mechanisms Presentation for design details



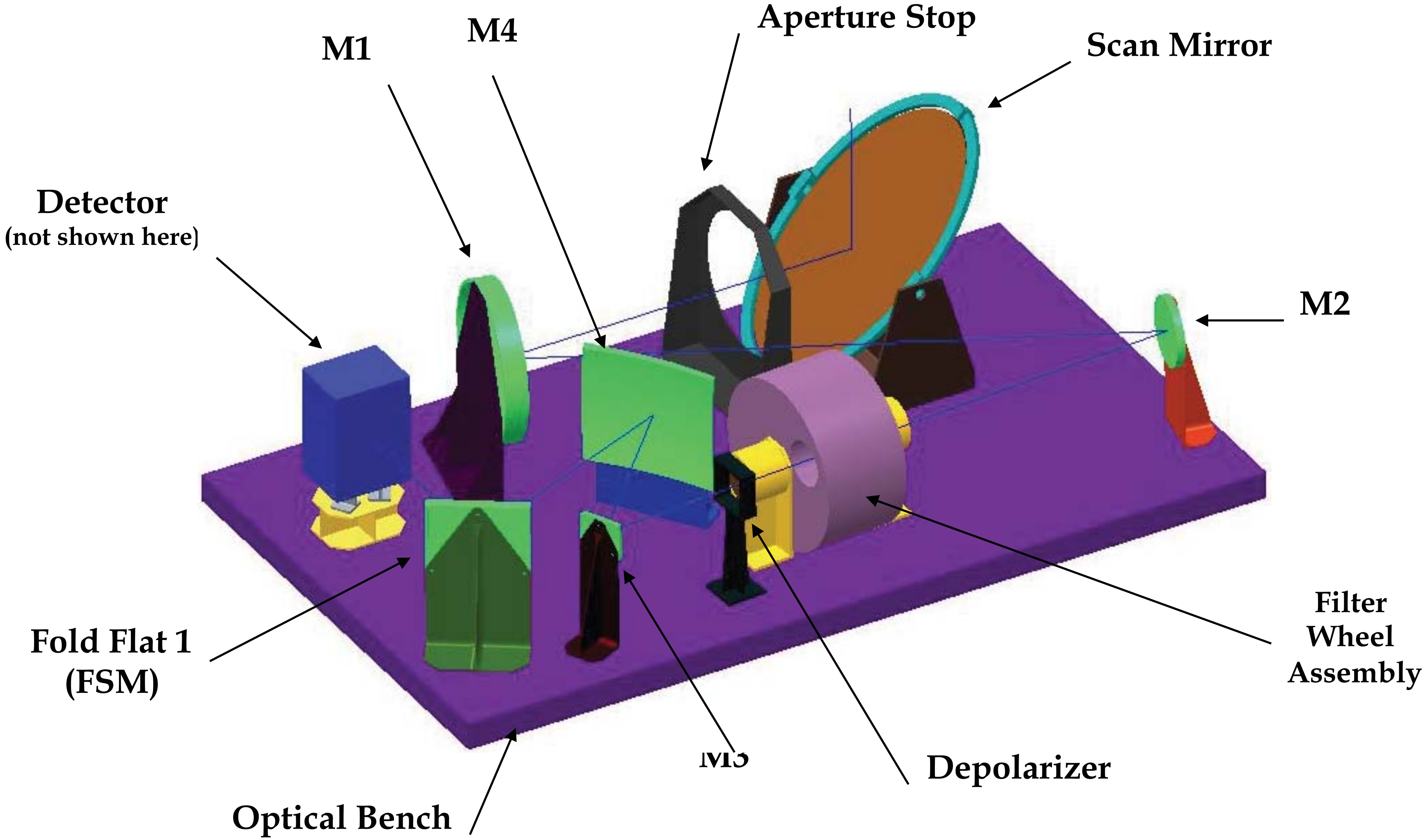
Note: Flexures would be oriented so that the line of action is through the c.g. of the instrument

Structure

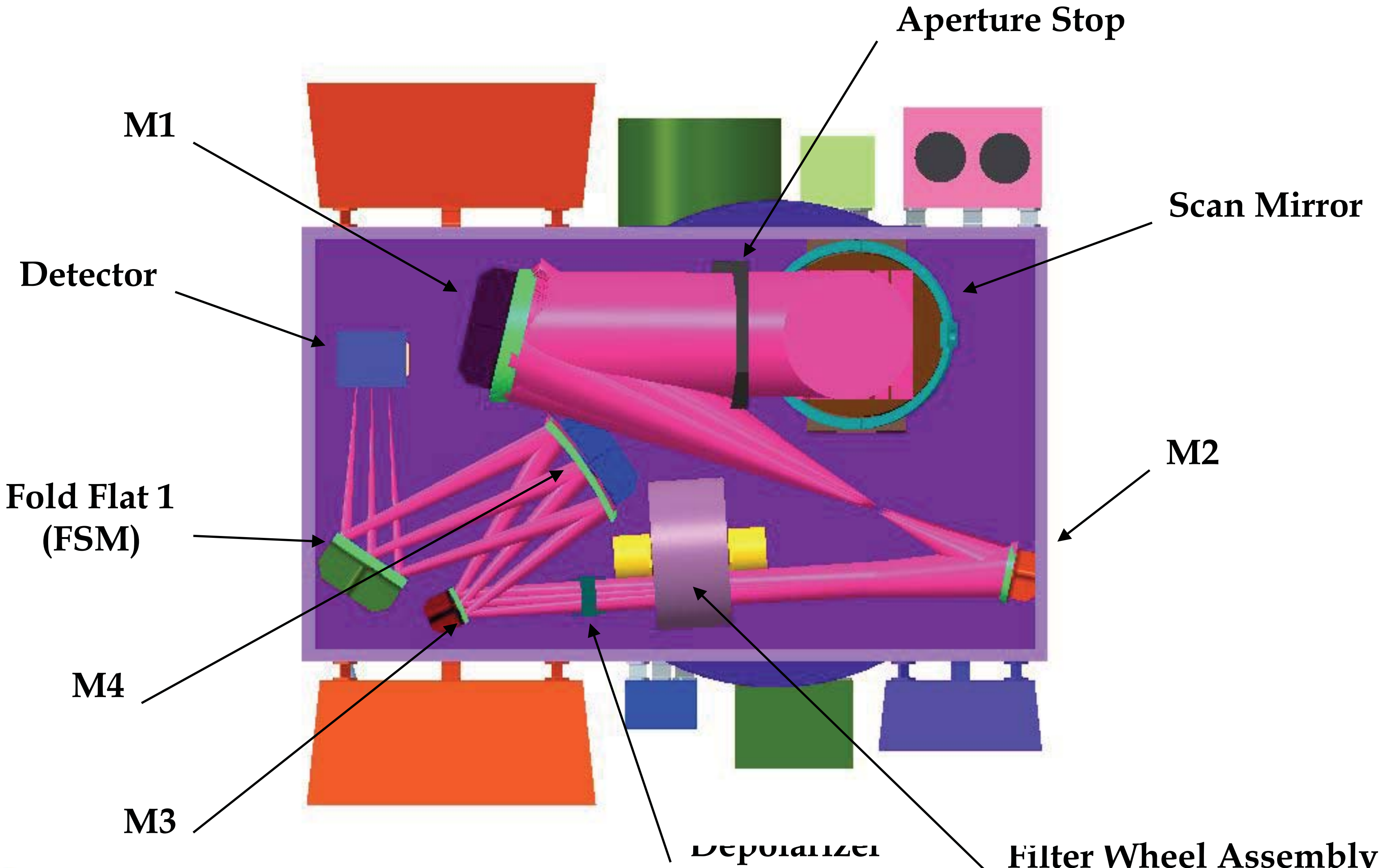


Contamination Cover
12 mm Alum Core
1 mm M55J f/s
Enclosure Panel 3
Nadir Panel
50 mm Alum Core
1.5 mm M55J f/s
Science Aperture Baffle
t = 2 mm M55J
Enclosure Panel 2
Enclosure Panel 1
Enclosure Panel 4
Optical Bench
50 mm Alum Core
1.5 mm M55J f/s
Diffuser Wheel Edge Cover (2)
t = 1 mm M55J
Enclosure Panels 1 – 4
25 mm Alum Core
1.5 mm M55J f/s

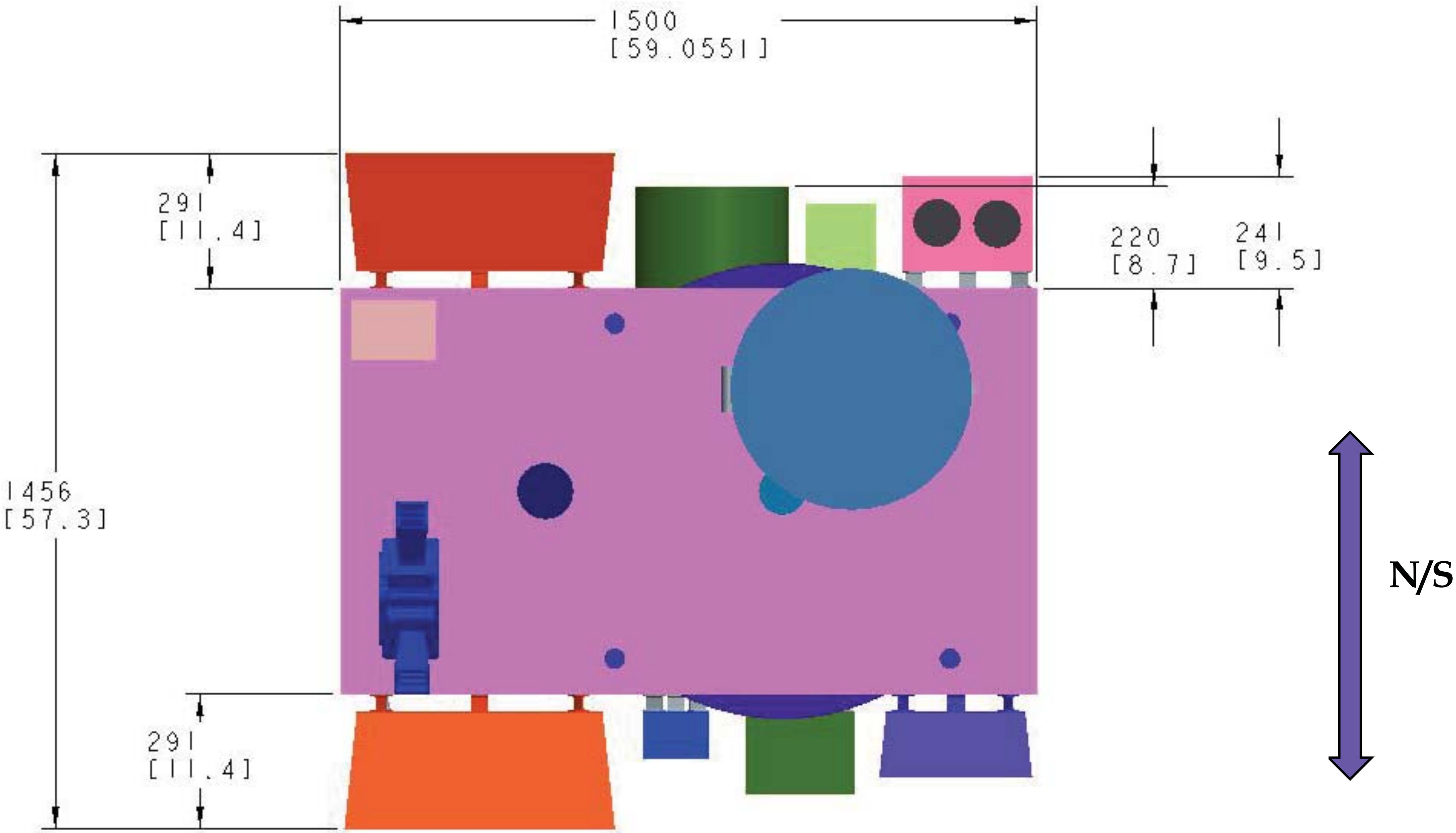
Optical Assembly



Optical Assembly

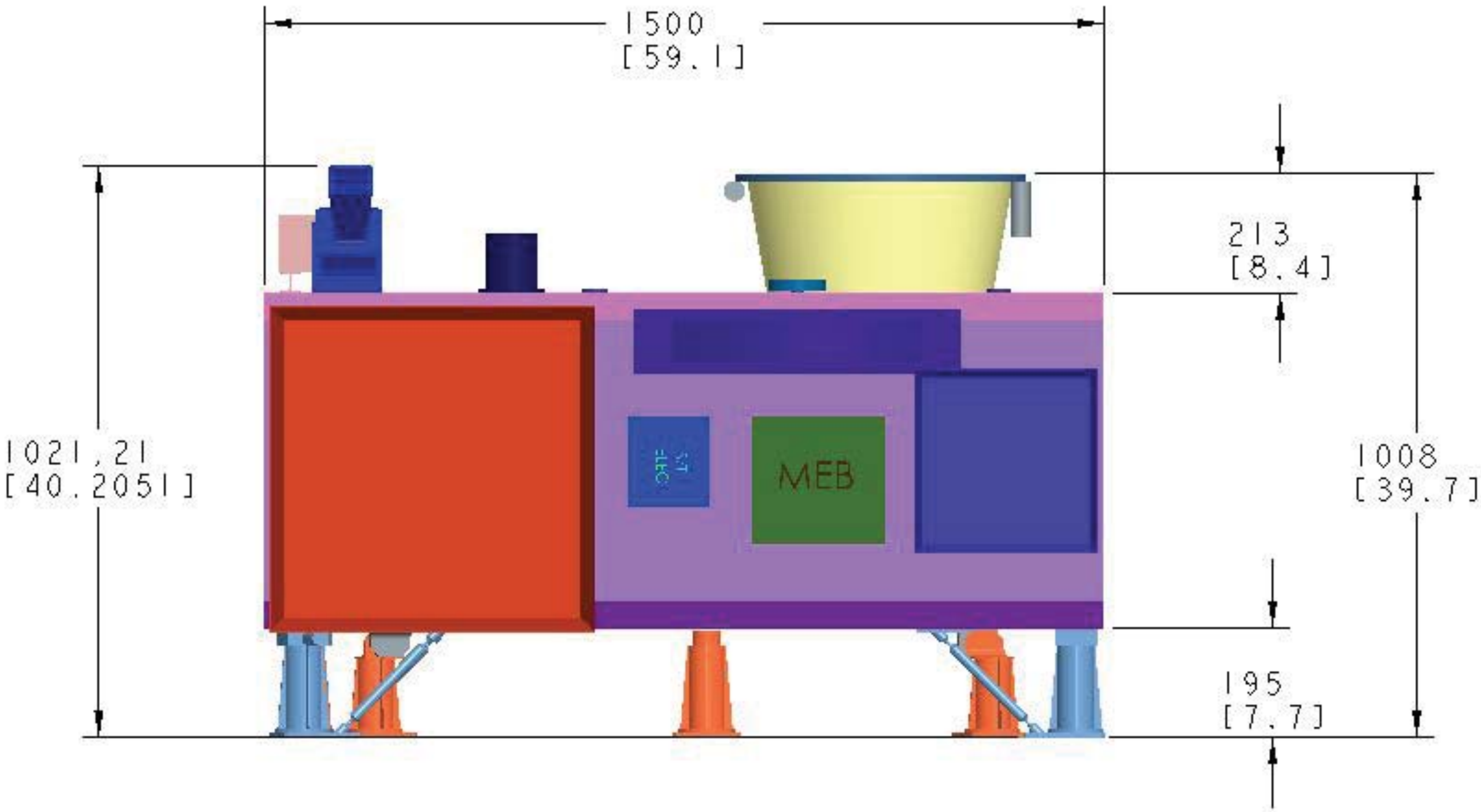


Dimensions



Dimensions in mm [in]

Dimensions



Dimensions in mm [in]

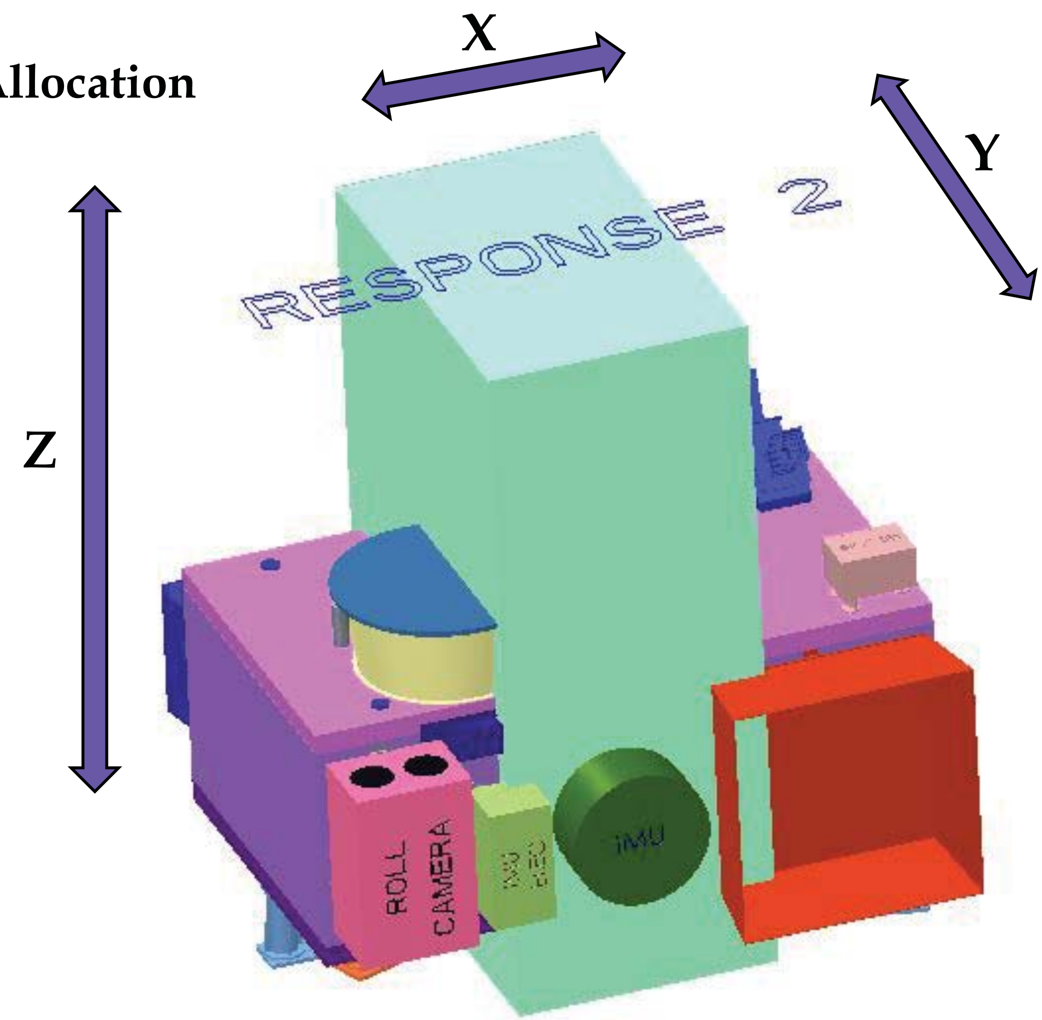
Engineering Allocations – Response 2

Integrated Design Capability / Instrument Design Laboratory

"Response 2" Volume & Mass Allocation

(E/W) X = 630 mm
(N/S) Y = 1010 mm
(Zenith) Z = 1650 mm

150 kg



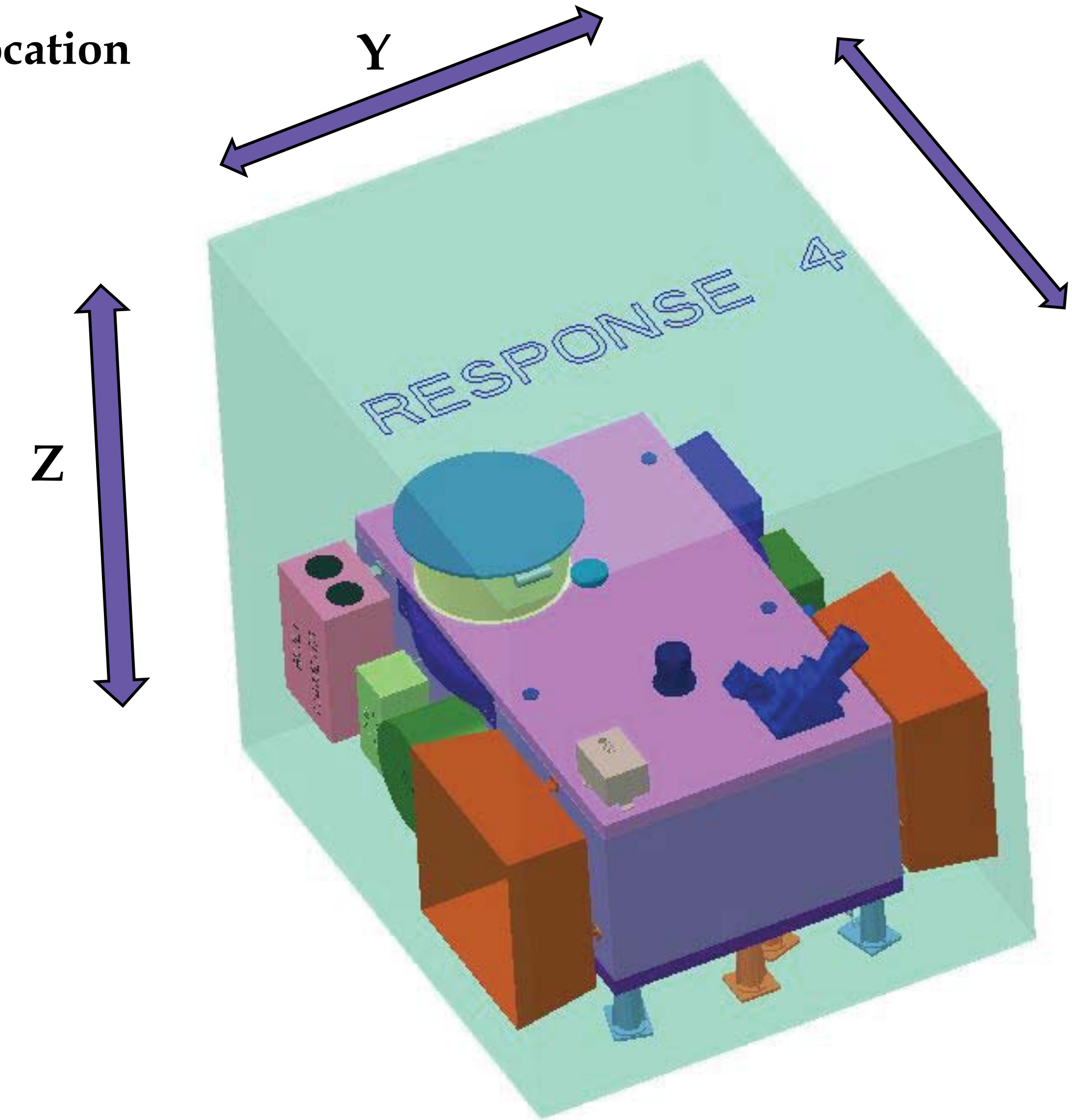
Engineering Allocation – Response 4

Integrated Design Capability / Instrument Design Laboratory

“Response 4” Volume & Mass Allocation

(E/W) X = 1800 mm
(N/S) Y = 1500 mm
(Zenith) Z = 1800 mm

300 kg

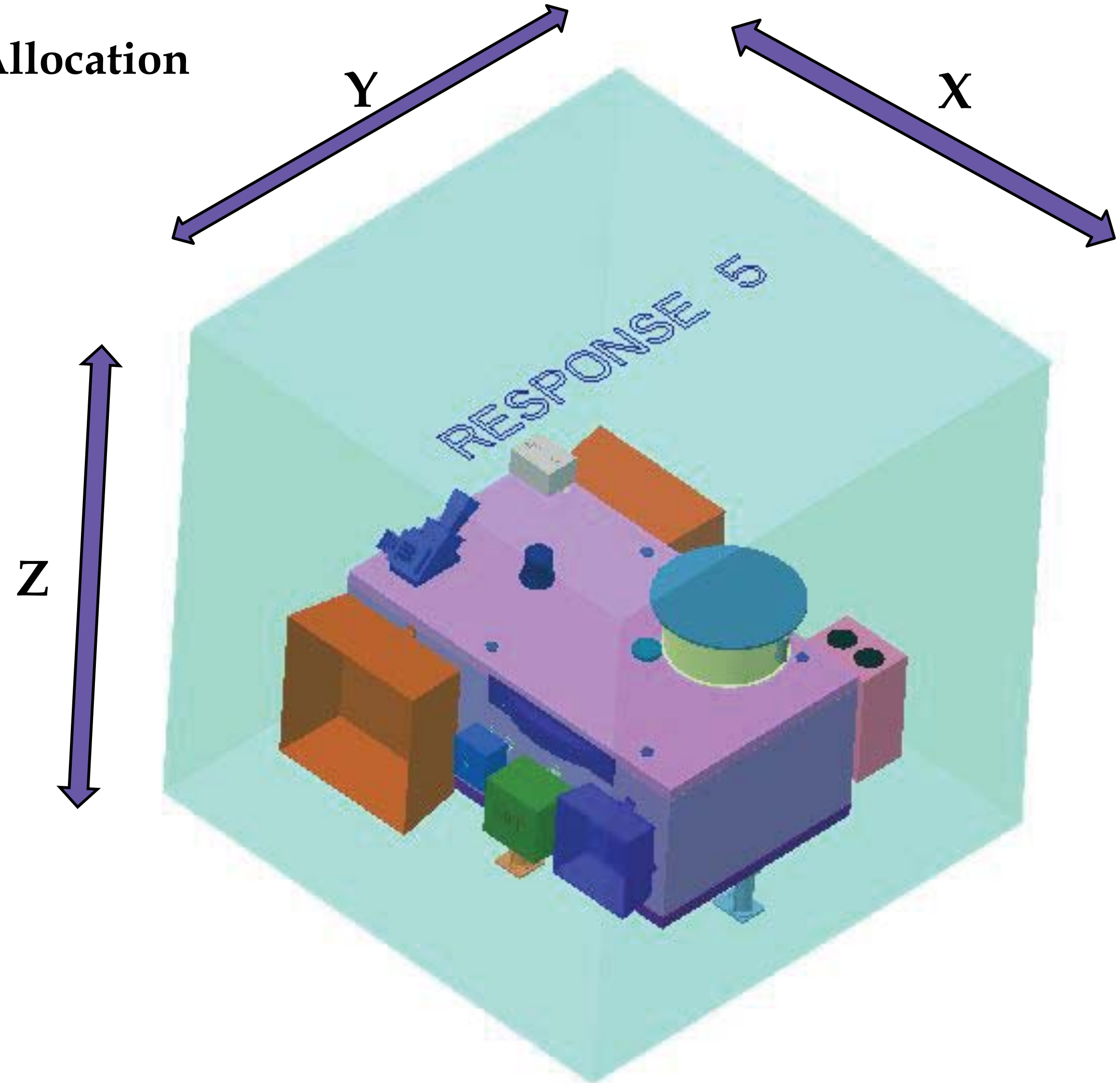


Engineering Allocation – Response 5

"Response 5" Volume & Mass Allocation

(E/W) X = 2000 mm
(N/S) Y = 2000 mm
(Zenith) Z = 2000 mm

250 kg

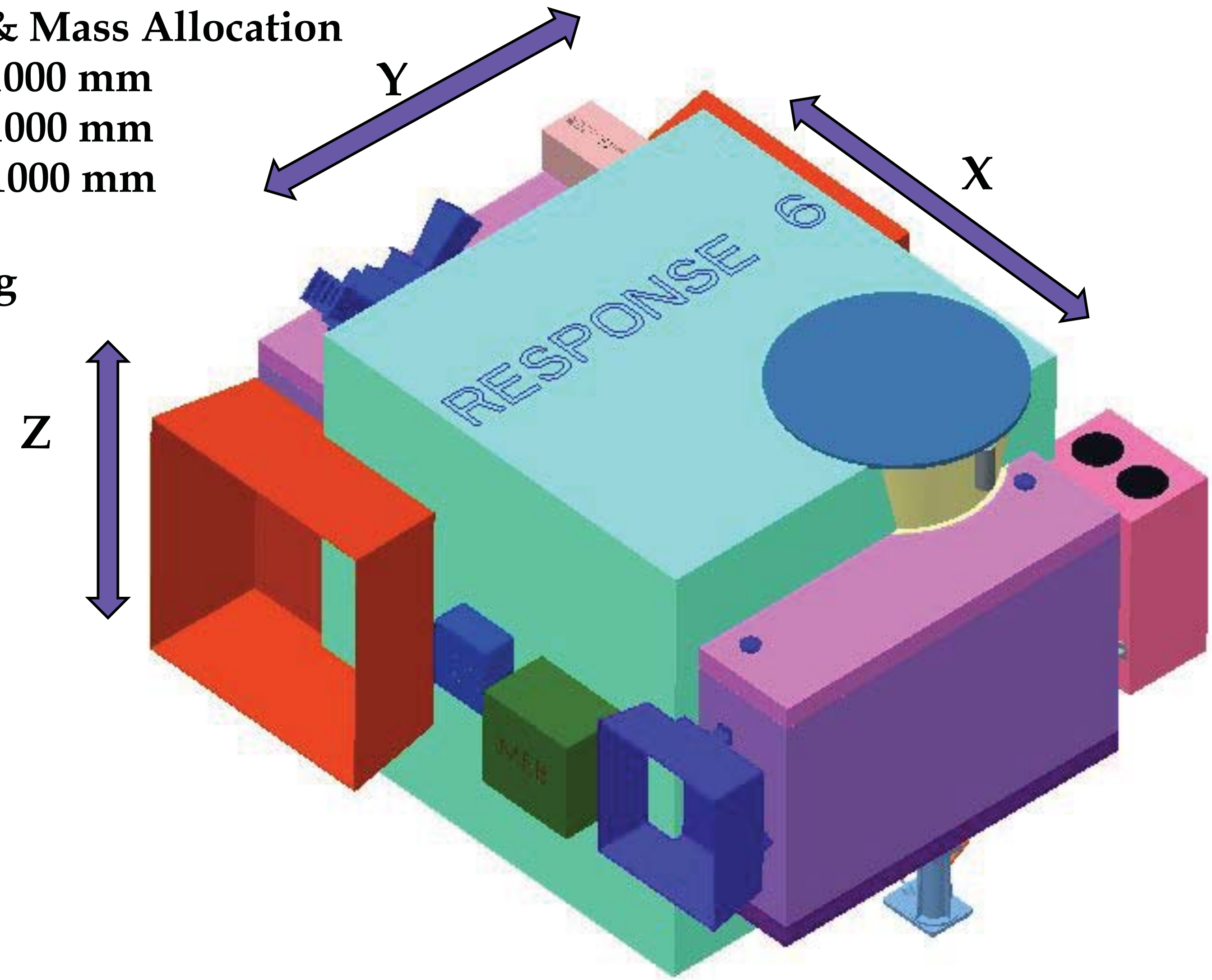


Engineering Allocation – Response 6

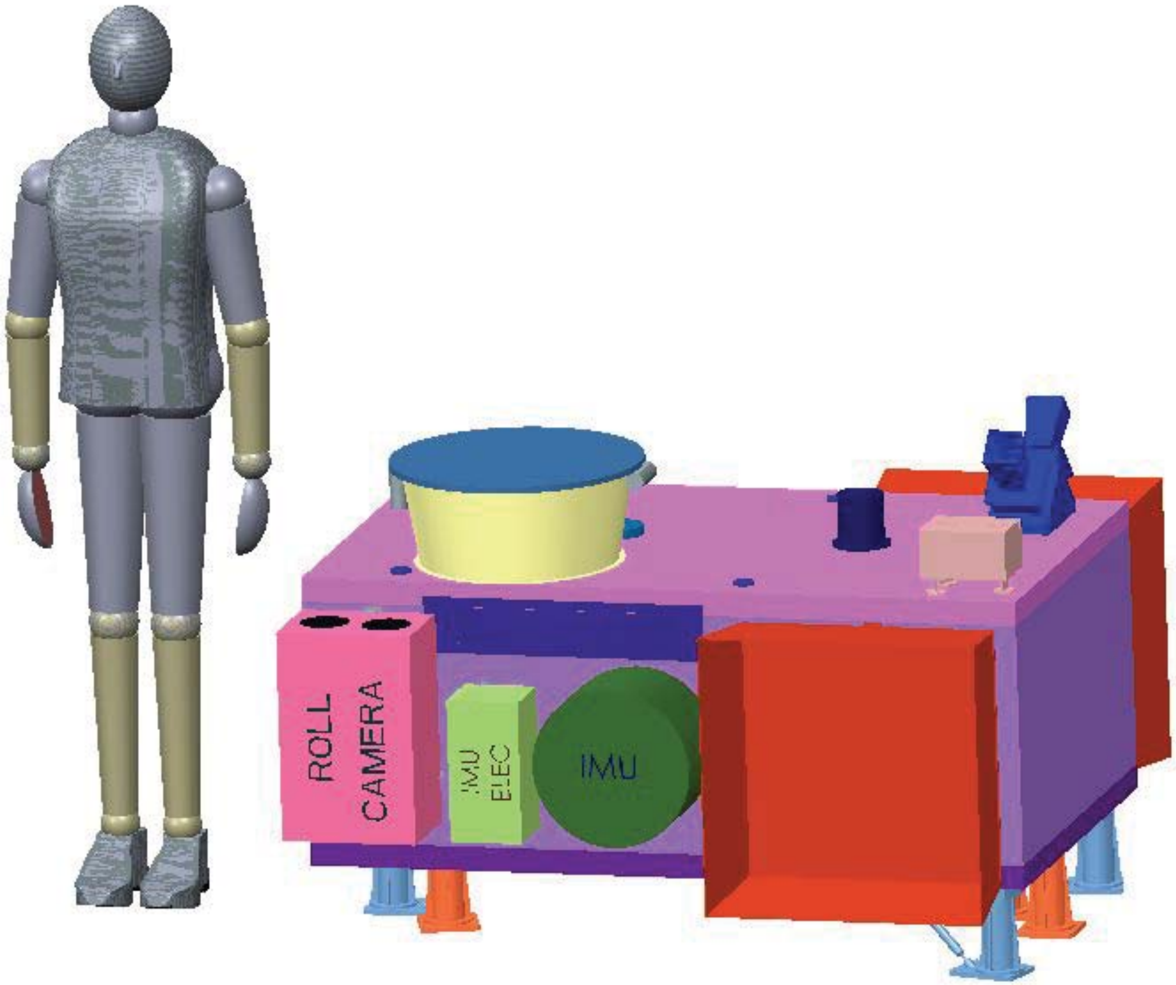
"Response 6" Volume & Mass Allocation

(E/W) X = 1000 mm
(N/S) Y = 1000 mm
(Zenith) Z = 1000 mm

1500 kg



Adam!!



Conclusions

- **There are no technology risks associated with the mechanical or structural design (i.e. standard materials as well as fabrication and assembly techniques for primary and secondary structure).**
- **The detector digitizer box is mounted on the outside of the instrument enclosure, approximately 10 inches from the detector.**
- **The instrument fits within the volume envelope for Engineering Allocation Responses 4 and 5. Mass requirements are 300 kg for Response 4 and 250 kg for Response 5.**
- **Stray Light Baffles are not represented in the CAD model but are accounted for in the MEL.**
- **The mounts for the Filter Wheel Assembly as represented in the CAD model are likely under designed. The mass in the MEL represents a more robust design for this mount that we feel is prudent.**
- **Thermal analysis completed late in the study week determined that the Detector radiator sunshade needed to be in the same plane as the Electronics radiator sunshade. This "standoff mount" is not represented in the CAD model but is included in the MEL.**
- **The Hosted Payload frequency requirements of 65 Hz lateral and 90 Hz longitudinal will likely be a challenge for an instrument of this size and mass.**
  - Early discussions with the S/C provider will likely be necessary to negotiate those requirements.

GEO CAPE Filter Radiometer (FR)

~ Mechanisms Presentation ~

Dick McBirney

Aug 12, 2014

There are five mechanisms in GeoCape 2 FR

These are hyperlinks to each mechanism in this file, but it may not be worth the trouble to use them…

Me1: Diffuser Wheel

Me2: Scan Mirror

Me3: Fast Steering Mirror

Me4: Jitter Suppression/Roll Correction System

Me5: Contamination Door

Me6: Filter Wheel Assembly

Mechanisms in the optical path

- **Locations of mechanisms within the optical path:**

Me5: Contamination Door

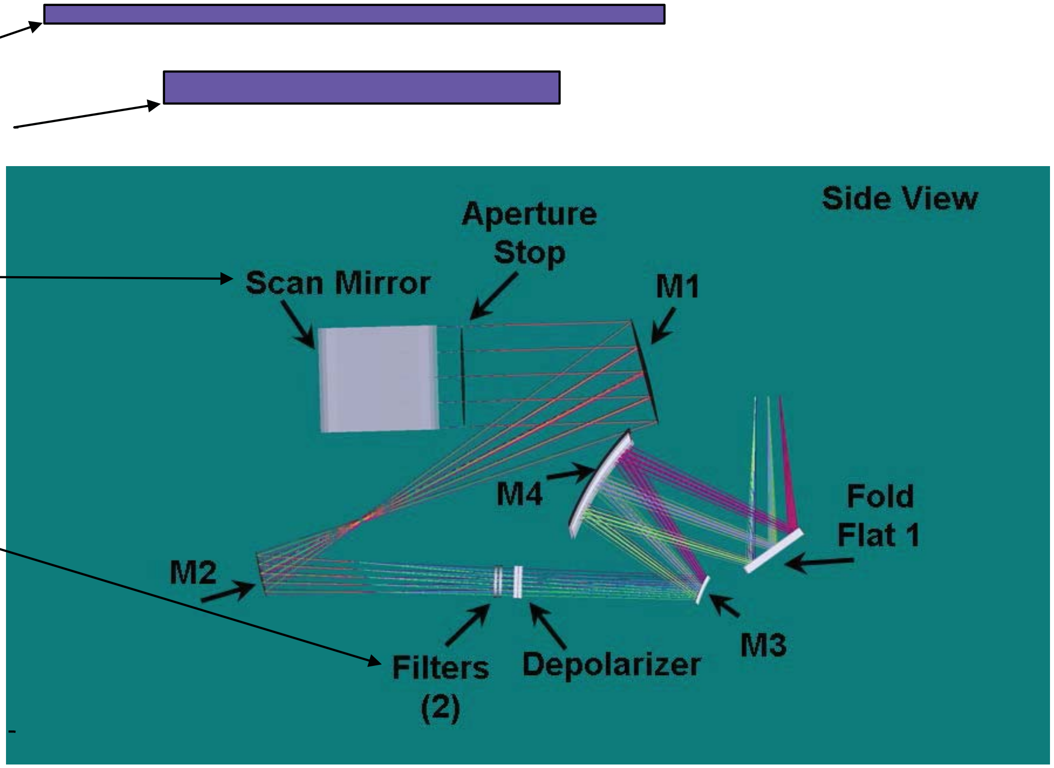
Me1: Diffuser Wheel

Me2: Scan Mirror Mechanism

Me3: Fast Steering Mirror Mechanism

Me6: Filter Assembly

Me4: Jitter Suppression/Roll Control System (not shown) (located between host S/C and instrument)



GEO CAPE FR Mechanisms Table 1/2

	Me1: Diffuser Wheel Mechanism ("DWM")	Me2: Scan Mirror Mechanism ("SMM")	Me3: Fast Steering Mirror ("FSM")	Me4: Jitter Suppression/ Roll Correction System ("JSS")	Me5: Contamination Door	Me6 Filter Wheel Assembly
Inertial Load	2X Φ350 mm diffusers (2.1 kg ea), one open position and 1 closed; MOI = ??	480mm x 280mm Scan Mirror, 2.6 kg Maximum MOI .082* kg-m^2 (*w/motor & encoder)	Φ120 mm Flat MOI = TBD	MOI = [Entire Instrument]	*Door diameter 706mm (27.8")* MOI TBD	5X Φ80mm filters (66 gm ea), and one "open" position in each of 10 wheels; Est. MOI = 167 Kg-cm^2
Stroke	360° rotation in 90° steps	+/- 5.1° tip/tilt at mirror (for science and solar cal views)	+/- 0.25 deg tip/ tilt		*270° rotation*	360° rotation in 60° steps for each wheel
Position Accuracy : Goal / *Achieved*	±0.5° / *±0.3° w/10 bit encoder*	0.1 arcsec / *0.08 arcsec w/24 bit encoder*	<0.1 arcsec / *TBD*	0.1 arcsec	*±5° in open position*	±0.5° / *±0.3° w/10 bit encoder*
Duty Cycle	<5%	0.16%; Step in 0.160 sec, stare as 50 filters are indexed	100%	100%	<5%	~10%; index in 0.2 sec, stare for ~2 sec
Bandwidth Goal / *Achieved*	low	"fast!" / *(step 0.4° in 160 millisec)*	High enough to cancel transmitted S/C jitter	Passive: As low as possible */Notional 1.7 Hz* Active: >1.7 Hz/*set by rate sensor sample rate*	One time deploy	Fast motion is desired

Red font To be confirmed

GEO CAPE FR Mechanisms Table 2/2

	Me1: Diffuser Wheel Mechanism ("DWM")	Me2: Scan Mirror Mechanism ("SMM")	Me3: Fast Steering Mirror ("FSM")	Me4: Jitter Suppression/ Roll Correction System ("JSS")	Me5: Contamination Door	Me6 Filter Wheel Assembly
Motion required / *Achieved*	Diffusers used during solar calibration. Select between 4 positions 90° apart. Select time <30 seconds	"fast!" / *1 arcsec step in 4ms, settle in 2ms, on both axes*	Jitter rejection to stabilize Beam on slit; High bandwidth Control	1) Low pass attenuation: angular motion decreases by -40db/decade above angular resonance frequency 2) Active damping: depends on closed loop performance	One time motion on command	Used during science data. Select between 50 filters on 10 wheels. Select time as fast as possible */ 0.2 sec per filter*
Launch Lock	No; "V" bearings on periphery and bearing on central shaft absorb launch loads	No, balanced mirror: 1.89kg	No, with light mass balanced mirror	Yes, three TiNi Frangibolts to lock 3DOF suspension	Yes, redundant HOP Latch	No, "V" bearings on periphery and axial bearing on central shaft absorb launch loads
Architecture	4 position, filter wheel-like device driven with stepper motor/gear	2 axis gimbal with limited range Torque Motors & 24 bit encoders	Traditional FSM; quad voice coils (BEI) with LVDTs (Kavlico)	Triple flexure tripod mount with three voice coil actuators controlled by rate sensors and roll camera	HOP Latch release, kickoff springs set deploy rate, torsion springs sustain rate and hold in open position	Ten 6-position wheels rotated through central female spline with stepper motor A
Comments	Should be balanced by placing heavy diffusers at 180°	Balanced mirror may not need launch locks	May not be required if SMM is fast enough and JSS is soft enough	Flexures remove high freq jitter; actuators remove low frequency jitter and roll angle error	Torsion springs hold Door in open position (no jettison, and no flopping during S/C maneuvers)	1 of 10 wheels selected by axial motion of male spline driven by stepper motor B

Red font To be confirmed

Me1: Diffuser Wheel Mechanism DWM 1/3

- **Primary Requirements:**
  - Wheel contains: four positions: 2 Diffusers, one open position, one closed position
  - Motion: rotate diffuser wheel to one of 4 positions at 90°
  - 90°Step time: <30 seconds
  - Position accuracy: ±0.5°
  - Diffuser size: 350mm x 10mm thick
  - Diffuser mass: 2.1 kg each, total of 4.2 kg; bending frequency = 887 Hz

4.2 Diffuser Mass

$dia_{diff} := 350mm$ $\quad thick_{diff} := 10mm$ $\quad \rho_{fusedSi} \equiv 2.2 \frac{gm}{cm^3}$

$$mass_{diff} := \frac{\pi}{4} \cdot dia_{diff}^2 \cdot thick_{diff} \cdot \rho_{fusedSi} \qquad mass_{diff} = 2.117\,kg$$

4.3 Diffuser resonant frequency

$E_{fused\_silica} := 71.7GPa$ $\quad \nu_{fused\_silica} := 0.17$ $\quad GPa \equiv 10^9 \cdot Pa$

$$DD := \frac{E_{fused\_silica} \cdot thick_{diff}^3}{12 \cdot \left(1 - \nu_{fused\_silica}^2\right)}$$

$$\omega_{n2} := \frac{10.21}{2 \cdot \pi \cdot \left(\frac{dia_{diff}}{2}\right)^2} \cdot \sqrt{\frac{DD}{\rho_{fusedSi} \cdot thick_{diff}}} \qquad \omega_{n2} = 887.351\,Hz$$

- **Derived Requirements:**
  - Diffuser wheel diameter: 971mm (38")
  - Balance: diffusers should be positioned diametrically opposite at 180° to roughly balance the wheel
  - Launch locks: not required; three wheel rim guide bearings and one center bearing absorb launch loads
- **Power Consumption:**
  - Given the mass MOI value of the wheel and the required indexing time, a power estimate could be created. Lacking those values, but impressed by the wheel size and probable friction torque to be overcome, the estimated power is 20 watts while indexing.

Me1: Diffuser Wheel Mechanism 2/3

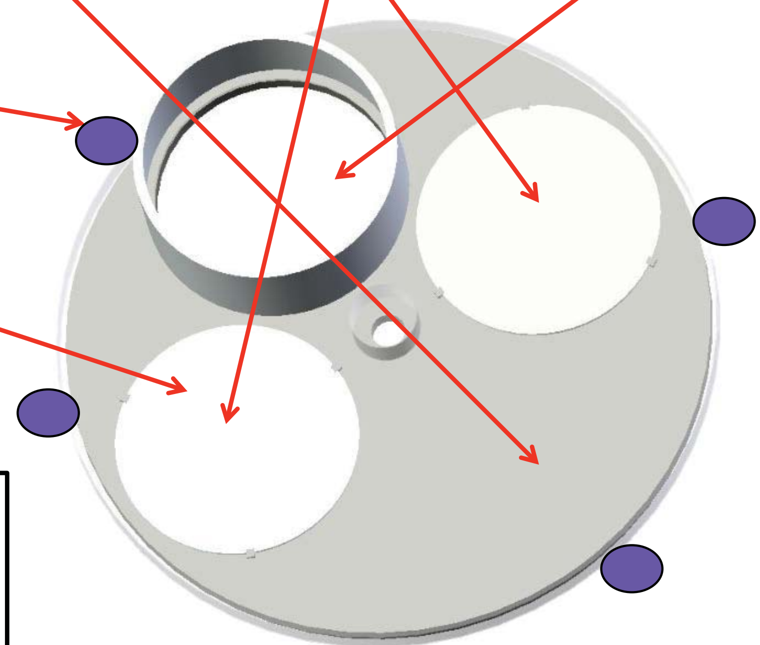
- **Proposed design:**
  - Φ971mm (38”) Wheel supported by four* peripheral guide bearings and one central bearing for axial support.
  - Two solar diffusers made of fused silica placed symmetrically for balance.
  - Stepper motor/gearbox drive a Delrin pinion gear that meshes with gear teeth on periphery of wheel (see next slide).
  - 10 bit digital rotary position encoder attached to central shaft for position feedback. (360°/ 2^10=21arcmin) (see next slide).

4.2 Diffuser Mass

$dia_{diff} := 350mm$ $\quad thick_{diff} := 10mm$ $\quad \rho_{fusedSi} \equiv 2.2 \frac{gm}{cm^3}$

$mass_{diff} := \frac{\pi}{4} \cdot dia_{diff}^2 \cdot thick_{diff} \cdot \rho_{fusedSi}$ $\quad mass_{diff} = 2.117 kg$

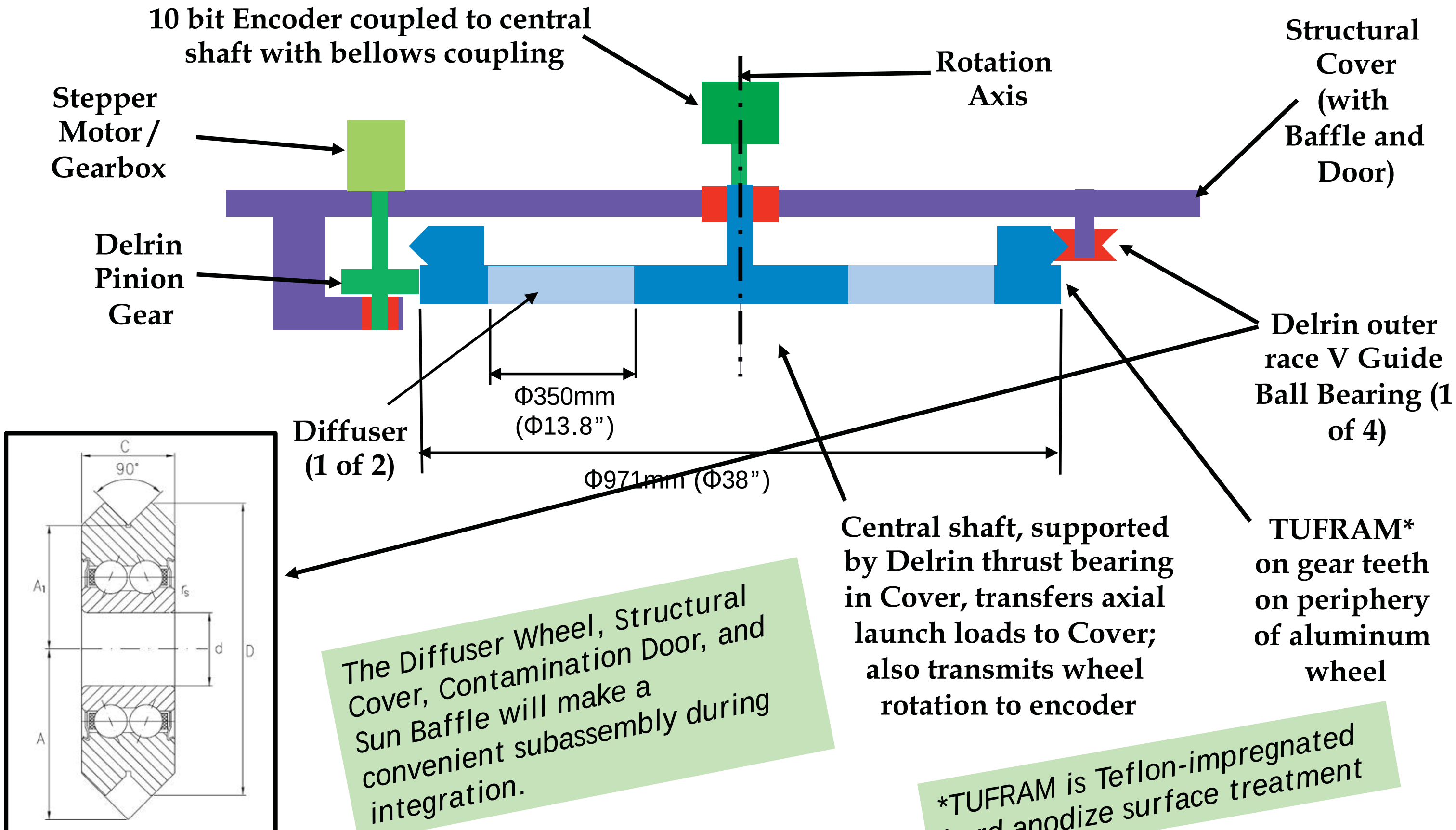
2X Φ350mm x 10mm thick diffusers (2.1 kg ea), one “open” position and 1 cover



(*three at 120°are ideal, but the housing is too narrow)

Me1: Diffuser Wheel Mechanism 3/3

- **Proposed design:**
  - Φ971mm (38”) Wheel supported by four peripheral guide bearings (two fixed, two spring loaded) and one central bearing for axial support.
  - 10 bit digital rotary position encoder attached to central shaft for position feedback. (360° / 2^10=21arcmin)
  - Stepper motor / gearbox with pinion gear driving spur gear mesh at periphery of wheel.
  - The peripheral guide bearings (two are adjacent to the heavy diffusers) engage a V near the OD of the wheel, eliminating the need for launch locks. Delrin on Tufram contact provides sliding surface if bearing rotation fails.



The Diffuser Wheel, Structural Cover, Contamination Door, and Sun Baffle will make a convenient subassembly during integration.

*TUFRAM is Teflon-impregnated hard anodize surface treatment

Me2: Scan Mirror Mechanism SMM 1/8

- **Primary requirements:**
  - Motion: Two axis tip/tilt of scan mirror, scanned in 0.4° steps.
  - Mirror travel range: ±5.1° on each axis.
  - Position knowledge accuracy: 0.1 arcsec ($1/2^{24}$ rev).
  - Beam dimensions at Scan Mirror: Φ250mm (9.8”) at 45° incidence.
  - Scan Mirror size and mass: oval 330mm x 500mm x 25.4 mm, est. at 50% lightweight.
  - Slew Dynamics: slew 10° on both axes in TBD sec.
- **Derived parameters:**
  - Scan Mirror
    - Mass: 3.64kg
    - MOI: 0.025 kg-m² and 0.103* kg-m² (*motor and encoder added to this axis)
  - Scan Dynamics:
    - Move Scan Mirror 0.4° in **<u>0.16 sec</u>**, then hold for (50 x 2 sec =) **<u>100 sec</u>** total stare time + (0.2 sec x 50 =) **<u>10 sec</u>** total filter index time, then repeat every 110.16 sec.

$$\boxed{\delta\theta := \frac{360\text{deg}}{2^{24}} \qquad \delta\theta = 0.077\,\text{arcsec}}$$

1.1 Mass and MOI

$1\text{arcsec} = 0.000278\text{deg}$

ULE glass $1\text{arcsec} = 4.848\text{microrad}$

Scan Mirror mass from dimensions, lightweight factor and density

lightweighting factor

$\rho_{ULE} := 2.21\frac{\text{gm}}{\text{cm}^3}$ $\quad a_{SM} := \frac{330}{2}\text{mm}$ $\quad b_{SM} := \frac{500}{2}\text{mm}$ $\quad LF := 50\%$

a and b are <u>half</u> the principal axes

$\text{thickness}_{SM} := 25.4\text{mm}$

$\text{mass}_{SM} := LF \cdot \rho_{ULE} \cdot \pi \cdot a_{SM} \cdot b_{SM} \cdot \text{thickness}_{SM}$ $\qquad \text{mass}_{SM} = 3.637\text{kg}$

1.1.1 Estimated Launch Load $F_{launch} := 15g \cdot \text{mass}_{SM} \cdot 3$ $\qquad F_{launch} = 360.842\text{lbf}$

1.1.2 Estimated Mirror Mass MOI

$$MOI_{aSM} := \text{mass}_{SM} \cdot \left[\frac{(a_{SM})^2}{4} + \frac{(\text{thickness}_{SM})^2}{12}\right] \qquad MOI_{aSM} = 0.02495\text{kgm}^2$$

$$MOI_{bSM} := \text{mass}_{SM} \cdot \left[\frac{(b_{SM})^2}{4} + \frac{(\text{thickness}_{SM})^2}{12}\right] \qquad MOI_{bSM} = 0.057\text{kgm}^2$$

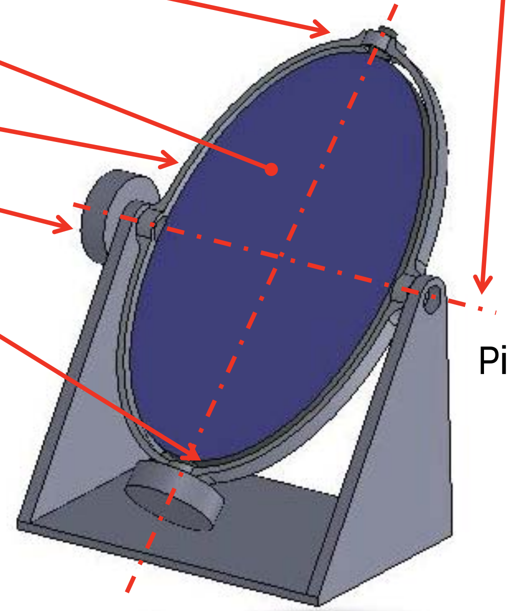
$\text{mass}_{motor} := 13\text{oz}$ $\qquad MOI_{motor} := \text{mass}_{motor} \cdot {b_{SM}}^2$ $\qquad MOI_{motor} = 0.023\text{kgm}^2$

<u>Assume encoder MOI = motor MOI</u>

$MOI_{bSM\_with\_MotorEnc} := MOI_{bSM} + 2 \cdot MOI_{motor}$ $\qquad \boxed{MOI_{bSM\_with\_MotorEnc} = 0.103\text{kgm}^2}$

Me2: Scan Mirror Mechanism 2/8

- **Proposed design:**
- **Light-weighted oval flat ULE glass mirror with integral stub shafts mated to inner motor/encoder rotors and inner ball bearings.**
- **Mirror mass: 3.64 kg.**
- **Launch locks:** *may not be required.*
- **Inner bearings mount in gimbal ring.**
  - (Flexpivot spring rates requires too much power to hold position)
- **Gimbal ring has integral stub shafts mated to outer motor/encoder rotors and outer ball bearings.**
- **Motors are limited angle Torquers (Aeroflex)**
- **Position sensors are 24 bit absolute encoders (Renishaw)**
  - Renishaw uses 1 nm resolution technology; 1 arcsec absolute accuracy is achieved in a 100mm diameter encoder – see slide 14
- **Pitch axis motor/encoder should be adjacent so as to maximize torsional resonant frequency and resultant pitch servo bandwidth (gimbal ring is too compliant).**
- **Yaw axis motor and encoder could be on opposite sides if mirror torsional stiffness is high and does not overly reduce yaw servo bandwidth.**



Me2: SMM Ball Bearing Selection 3/8

- **Two Barden SN541TA bearings are used per axis.**
- **Each bearing will absorb 361/2=180 lbf launch load**

1.6 Scan Mirror Launch loads

$Accel_{launch} := 15g$ launch load g factor $rms\_factor := 3$

$Launch\_Force_{SM} := mass_{SM} \cdot Accel_{launch} \cdot rms\_factor$ $Launch\_Force_{SM} = 361\,lbf$

1.2 Scan Mirror Bearing Friction Torque

Bearing Dimensions $OD := 1.5in$ $ID := 1.06in$

friction coeff of ball bearing $f_b := 0.002$

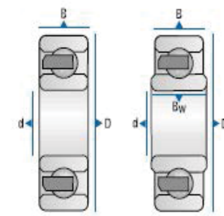
axial bearing preload $F_{axial} := 15lbf$

$T_f := f_b \cdot \left(\frac{OD + ID}{2}\right) \cdot F_{axial}$ $T_f = 4.339N \cdot mm$ $T_f = 0.614in \cdot ozf$

total ball bearing friction torque per axis $T_{total\_fric\_torq} := 2 \cdot T_f$ $T_{total\_fric\_torq} = 1.229in \cdot ozf$

DEEP GROOVE THIN SECTION (INCH)

Bore Diameters: 15.875mm to 39.688mm
- Open, shielded and sealed



500 SERIES BASIC BEARING NUMBER	Bore Diameter d mm	inch	Outside Diameter D mm	inch	Width Outer Ring B mm	inch	Width Inner Ring Bw mm	inch	Maximum Shaft/Housing Radius Which Bearing Corner Will Clear r Max. mm	inch	nd²	Static Capacity Radial C_0 (lbs.)	Thrust T_0 (lbs.)	Basic Dynamic Load Rating C (lbs.)
SN541ZA	26.988	1.0625	38.100	1.5000	6.350	0.2500	6.350	0.2500	0.38	0.015	0.2344	256	623	484
SN541TA	26.988	1.0625	38.100	1.5000	6.350	0.2500	6.350	0.2500	0.38	0.015	0.2813	477	764	552
A541ZA	26.988	1.0625	38.100	1.5000	6.350	0.2500	7.142	0.2812	0.38	0.015	0.2344	367	376	603
A541T	26.988	1.0625	38.100	1.5000	6.350	0.2500	7.142	0.2812	0.38	0.015	0.2500	392	401	629

- **This bearing has an OD of 1.5”, ID of 1.0625”, and a width of 0.250”**
- **With an axial preload of 15 lbf, the bearing friction torque per axis is estimated at 4.3N-mm (0.61 in-ozf) x 2 bearings = 6.8N-mm (1.23 in-ozf)**

Me2: SMM Torque Motor Selection 4/8

- **We will use an Aeroflex model TQ25-25PA torque motor:**
  - Mass: 0.37 kg (13 oz)
  - Size: 2.5” OD x 0.250“ ID(*) x 1.00“ w (*need custom design w/larger ID)
  - Torque gain: 27 in-ozf/amp
  - Max continuous torque: 25 in-ozf

TQ25 Series

Basic Part No.	Peak Torque (in. oz.)	Peak Power (watts)	Continuous Torque (in. oz.)	Angular Excursion (degrees)	Torque Sensitivity (in-oz/amp)	Resistance at 25°C (ohms)	Weight (oz)	Outer Diameter (inch)	Width (inch)	Inner Diameter (Inch)	Torque Curve
TQ25-37PKA	40	95	10	30	–	15	6	2.5	0.500	0.625	–
TQ25-26PA	52	96	40	50	11	4.3	7	2.5	1.000	0.250	D
TQ25-14PA	80	180	25	50	9	2.24	13	2.5	1.000	0.250	D
TQ25-25PA	80	223	25	50	27	25.4	13	2.5	1.000	0.250	D
TQ25-2P	80	140	25	50	27	16	13	2.5	1.000	0.250	–

Me2: SMM Torque Motor 5/8

- **Limited Angle Torque Motor**
  - No commutation
  - Very smooth torque curve (no torque ripple)
    - torque gain variation with angle (Curve D) varies control loop gain with position; but this is normally not a concern
  - Low electrical time constant
  - Direct drive, no transmission issues
  - Redundant windings
  - Tends to be slightly larger than commutating equivalent
  - Has flight heritage

tp://aeroflex.com/ams/motion/datasheets/motion-motors-lat.pdf

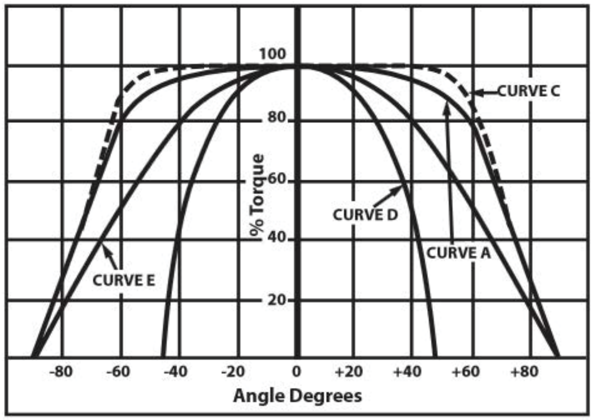


Figure 1: Performance Curves

Me2: SMM Encoder 6/8

- **in 1990, BEI presented a paper describing a 15” diameter, 24 bit encoder (this was the state of the art in 1990)**
- http://docs.jach.hawaii.edu/JCMT/a/019_encoders/07/BEI%20ITEK%20presentation%20of%2024%20bit%20encoder.pdf
- **In 2014, Renishaw can achieve “32 bit resolution” at a rate of 1/40usec = 25KHz**
- http://www.renishaw.com/en/resolute-rotary-angle-absolute-encoder-options--10939
- http://resources.renishaw.com/en/details/data-sheet-rexa-ultra-high-accuracy-absolute-angle-encoder--44234

$$\frac{1}{40 \cdot 10^{-6}\,\text{sec}} = 25000\,\text{Hz}$$

This entire process of operations and calculations take less than 40 microseconds from start to finish.

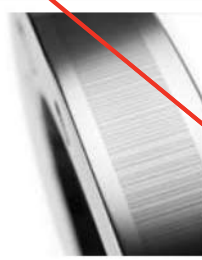
The activity doesn't even stop there, whilst it's waiting for the next request, the DSP calculates the optimum set-up for the next photo for the conditions and speeds being experienced, readying itself for the next position request.

High speed operation meets ultra-fine resolution

Top

RESOLUTE's performance is the combination of ultra-fine resolution and high speed. How is this possible?

RESOLUTE monitors the speed of the axis and varies the LED flash parameters accordingly. This is one of the keys to achieving exceptionally low jitter, at medium / low speeds and at stand-still, on the same encoder that can hit 100 metres/second (36000 rev/min on a 52 mm ring). RESOLUTE can even be switched on at high speed and yet it automatically optimises itself in a few milliseconds – considerably less time than the 250 ms or so that it takes the servo amplifier to power-up reset!



- REXA ultra-high accuracy ring with ±1 arc second total installed accuracy with dual readheads

REXA total installed accuracy grades:

REXA diameter	Total installed accuracy (with 2 readheads)
⩾100 mm	±1 arc second
75 mm	±1.5 arc second
⩽57 mm	±2 arc second

$$\frac{360\text{deg}}{2^{32}} = 0.000302\,\text{arcsec}$$

Me2: SMM Performance 7/8

- **With the mirror MOI determined, the torque motor selected, and the bearing friction torque defined, we can estimate the performance:**
  - The motor/mirror/encoder is operated as a closed position loop, but performance can be estimated by assuming we:
    1. Accelerate the mirror for 80 millisec with +17 in-ozf torque
    2. Decelerate the mirror for 80 millisec with -17 in-ozf torque
- **So the SMM can step 0.4° in 160 millisec**
- **The power consumption during each step is 10.3 watts**

1.4 SMM Motor Power consumption

$R_{motor} := 25.4\,ohm$ $\quad K_T := 27 \cdot \frac{in \cdot ozf}{A}$ $\quad I_{motor} := \frac{T_{IandF}}{K_T}$ $\quad I_{motor} = 0.635A$

$Power_{motor} := I_{motor}^2 \cdot R_{motor}$ $\quad Power_{motor} = 10.253W$

$V_{motor} := I_{motor} \cdot R_{motor}$ $\quad V_{motor} = 16.138V$

1.3 Scan Mirror Performance

After each stare, the SMM steps 0.4 deg $\theta_{step} := 0.4deg$ $\quad \frac{2048 \cdot 250m}{2 \cdot 36000km} = 0.407deg$

Assume a constant torque to move halfway, then constant negative torque to stop the motion

Assume time of half step acceleration $t_{half\_step} := 0.08sec$ $\quad \theta = \frac{1}{2} \cdot \alpha \cdot t^2$

$\alpha_{SM} := 2 \cdot \frac{\frac{\theta_{step}}{2}}{(t_{half\_step})^2}$ $\quad \alpha_{SM} = 62.5\frac{deg}{sec^2}$ $\quad \alpha = 2 \cdot \frac{\theta}{t^2}$

$torque_{bSM} := MOI_{bSM\_with\_MotorEnc} \cdot \alpha_{SM}$

$torque_{bSM} = 112.459N \cdot mm$ $\quad torque_{bSM} = 15.926in \cdot ozf$

total inertial and friction motor torque reqd $\quad T_{IandF} := torque_{bSM} + T_{total\_fric\_torq}$ $\quad T_{IandF} = 17.154in \cdot ozf$

The motor can exert $T_{continuous} := 25in \cdot ozf$

Since the duty cycle is very low, the average power is low:

1.5 Duty Cycle and average power

$time_{avg\_int\_time} := 2.0sec$ $\quad N_{filter} := 50$

$duty\_cycle := \frac{2 \cdot t_{half\_step}}{N_{filter} \cdot time_{avg\_int\_time}}$ $\quad duty\_cycle = 0.16\%$

$P_{average} := Power_{motor} \cdot duty\_cycle$ $\quad P_{average} = 0.016W$

Me2: Scan Mirror Mechanism 8/8

- **Excerpt from 2010 GeoCape Mechanisms presentation:**
- **"Motion**
  - E-W DOF: step over 1.1 arc-sec and settle in <250 millisec, repeat once per second"
- **"Image Stability**
  - Goal of 0.5 arc-sec (0.5 arc-sec on N-S DOF, 0.25 arc-sec on E-W DOF)"
- **"Scan Mirror mechanism is *on the edge of what is achievable*. A separate, intensive study should be performed to determine feasibility."**

- **2014 Technology is better:**
- *An encoder resolution of 0.1 arcsec (24 bit resolution) was the state of the art achieved by BEI in 1990 with a 15" diameter encoder, but Renishaw – and maybe others – can now achieve 30 bit resolution at that diameter.*

BEI data from 1990

EXAMPLE OF INDUSTRY FIRSTS RESULTING FROM ITEK IR&D ARE:

1959 First 17 Bit Optical Encoder (RD17 - 10" Gray Code)

1966 First 20 Bit Optical Encoder (DIGISEC® BD)

1968 First 21 Bit Optical Encoder (RA21/158)

1971 First Redundant Absolute Encoder

1975 First High Resolution Absolute Encoder with LED Illuminators (RAL18/106)

1977 First 22 Bit Optical Encoder with X64 Multiplier (RA22/158)

1980 First Multiplexed, Hybrid Code Encoder (MicroSeries®)

1982 First 10 Inch Thru-Hole, 21 Bit Spacecraft Encoder

1990 First 24 Bit Optical Encoder with LED Illuminators.

ENCODER CAPABILITIES

OUTSIDE DIAMETER	INSIDE DIAMETER	HIGHEST RESOLUTION STANDARD	HIGHEST RESOLUTION OPTIONAL
1.6 INCH	SHAFT	16 BITS	-
2.3	SHAFT	17 BITS	-
3.5	SHAFT	18 BITS	-
4.0	1.0 INCH	17 BITS	-
5.0	2.0 INCH	19 BITS	-
6.0	2.25 INCH	19 BITS	21 BITS
8.0	4.0 INCH	20 BITS	21 BITS
10.0	6.0 INCH	21 BITS	23 BITS
15.0	8.0 INCH	24 BITS	-

Me3: FSM (Fast Steering Mirror) 1/4

- **Primary Requirements**
  - Motion: Two axis tip/tilt of fold mirror.
  - Travel range: ±0.25° on each axis.
  - FSM mirror size: 172 mm x 140mm x 5mm flat, made of ULE.
  - Dynamics: bandwidth must be sufficient to reject angular jitter imposed on GeoCape FR instrument from S/C.
- **Derived Performance**
  - FSM mirror mass: <u>266 grams</u>
  - Bandwidth: the required bandwidth of the FSM should be minimal; for example, if the passive instrument mount could achieve an angular resonant frequency of, say, 1 Hz, the required FSM bandwidth could be as low as 10 Hz, depending on the results of a detailed analysis of the jitter attenuation required by the instrument.
- **Power Consumption**
  - Power consumption is minimal: to remove a 50 Hz, ±0.1° sinusoidal jitter requires 1.9 W average.

2.1 power consumption of FSM Voice Coil Actuator (VCA)

torque gain of the VCA $K_{T\_VCA} := 2.85 \frac{lbf}{amp}$ coil resistance is $R_{VCA} := 15ohm$

radius of the VCA $r_{VCA} := 2.5in$

torque gain of the VCA $K_{\theta\_VCA} := K_{T\_VCA} \cdot r_{VCA}$ $K_{\theta\_VCA} = 7.125 \frac{in \cdot lbf}{amp}$

Mass of the Fast Steering Mirror (FSM) is:

ULE $\rho_{ULE} = 2.21 \frac{gm}{cm^3}$ $a_{FSM} := 172mm$ $b_{FSM} := 140mm$ $thick_{FSM} := 5mm$

$mass_{FSM} := \rho_{ULE} \cdot a_{FSM} \cdot b_{FSM} \cdot thick_{FSM}$ $mass_{FSM} = 0.266kg$

MOI of the FSM is:

$$MOI_{bFSM} := mass_{FSM} \cdot \left[\frac{(b_{FSM})^2}{4} + \frac{(thick_{FSM})^2}{12}\right] \qquad MOI_{bFSM} = 1304.37kgmm^2$$

$$MOI_{aFSM} := mass_{FSM} \cdot \left[\frac{(a_{FSM})^2}{4} + \frac{(thick_{FSM})^2}{12}\right] \qquad MOI_{aFSM} = 1968.51kgmm^2$$

assume a sinusoidal motion of the FSM at a frequency "f" and a half amplitude of A_o". the peak angular acceleration is α_{max} $A_o := 0.1deg$ $f := 50Hz$

$\alpha_{max} := 4 \cdot A_o \cdot \pi^2 \cdot f^2$ $\alpha_{max} = 9.87 \times 10^3 \frac{deg}{s^2}$

so the max torque is $T_{max} := MOI_{aFSM} \cdot \alpha_{max}$ $T_{max} = 3.001in \cdot lbf$

so the max current is $I_{max} := \frac{T_{max}}{K_{\theta\_VCA}}$ $I_{max} = 0.421A$

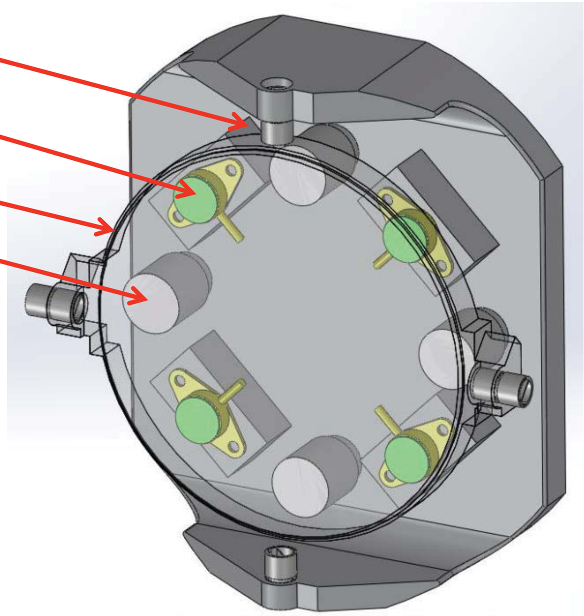
the max peak power is $P_{peak} := R_{VCA} \cdot I_{max}^2$ $P_{peak} = 2.661W$

the average power for a sinusoid is $P_{avg} := \frac{P_{peak}}{\sqrt{2}}$ $P_{avg} = 1.882W$

Me3: FSM 2/4

- **Proposed design: traditional Fast Steering Mirror mechanism:**
  - Flat mirror mounted on 2 Flexpivot bearings in gimbal ring;
  - Gimbal ring mounted on 2 Flexpivot bearings attached to base.
  - Four voice coil actuators attached to back of mirror;
  - Four position sensors attached to the back of the mirror. DITs are shown, but LVDTs are recommended; see slide 45.
  - Using push/pull actuation minimizes the dynamic radial loads on the bearings and gimbal ring.
- **Alternate design choices**
  1. The mirror could be supported by a center post with two flexural cuts to provide tip/tilt motion; this would eliminate 4 Flexpivot bearings and would eliminate the flexural compliance of the gimbal ring.
  2. Each pair of actuators and sensors could be aligned radially to eliminate crosstalk; the tradeoff is between (a) the reduced operating radius of the inner pair of components and (b) the complexity of extracting 2D on-axis angular position data from sensors that sense a combination of both tip and tilt motion.

This figure shows an FSM with a circular mirror from a previous study; except for the rectangular shape, the design for GEO CAPE FR would be similar.



"DIT" = Kaman Differential Impedance Transducer
"LVDT" = Kavlico Linear Variable Differential Transformer

Me3: Voice Coil Actuator 3/4

- **Pairs of VCAs are used in push/pull mode to tip and tilt the FSM**

BEI

"VCA is shown partially disassembled to see the coil windings; in operation, the windings are always totally immersed in the magnetic field to ensure a linear current>force gain over the stroke of the actuator."

P/N	TYPE	Peak Force		Continuous Stall Force		Total Stroke		Actuator Constant		O.D./ Width		Length (@ mid-stroke)	
		N	lb	N	lb	mm	in	N/√watt	lb/√watt	mm	in	mm	in
LA15-16-024A	CYL	88.96	20	24.47	5.5	6.35	0.25	5.827	1.31	38.1	1.5	39.62	1.56

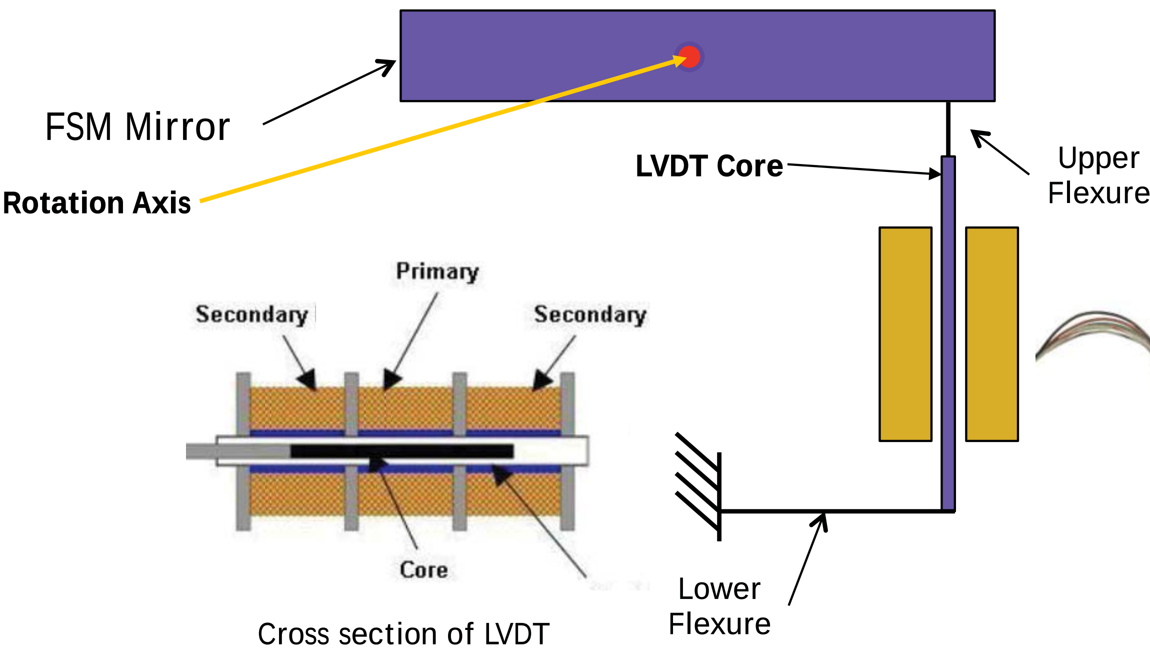
LA15-16-024A
Linear Voice Coil Actuators

WINDING CONSTANTS *	UNITS	TOL	SYMBOL	WDG A	WDG B
DC RESISTANCE	OHMS	± 12.5%	R	4.7	15.0
VOLTAGE @ F_P	VOLTS	NOMINAL	V_P	33.0	58.6
CURRENT @ F_P	AMPERES	NOMINAL	I_P	7.02	3.91
FORCE SENSITIVITY	LB/AMP	± 10%	K_F	2.85	5.12
	N/AMP	± 10%		12.68	22.77
BACK EMF CONSTANT	V/FT/SEC	± 10%	K_B	3.86	6.94
	V/M/SEC	± 10%		12.68	22.77
INDUCTANCE ****	MILLI-HENRY	± 30%	L	1.25	4.05

ACTUATOR PARAMETERS *	UNITS	SYMBOL	VALUE
PEAK FORCE **	LB	F_P	20.0
	N		89.0
CONTINUOUS STALL FORCE **	LB	F_{CS}	5.5
	N		24.47
ACTUATOR CONSTANT	LB/√WATT	K_A	1.31
	N/√WATT		5.83
ELECTRICAL TIME CONSTANT	MICRO-SEC	τ_E	270
MECHANICAL TIME CONSTANT	MILLI-SEC	τ_M	1.28
POWER I^2R @ F_P	WATTS	P_P	232
STROKE	± INCHES		0.125
	± MM		3.18

Me3: LVDT 4/4

Pairs of LVDTs are used in differential mode to measure the angular tip/tilt deflection of the FSM.
http://pre.kav.com.s3.amazonaws.com/downloads/Industrial%20LVDT.pdf



Cross section of LVDT

Photo is for illustration only; not to scale

Key Product Features

Excitation Voltage	3.0 to 26 VRMS
Excitation Frequency	60 to 5,000 Hz
Temperature Range	-65°F to +450°F
Measurement Range	.010" to 20.00"
Accuracy	±0.5% FS Typical (-65° to +250° F)
Vibration Capability	Over 100 G's
Accelerated Shock	500 G's
Pressure	10,000 psi
Linearity	±0.25% FS Typical
Environmental	MIL-STD-810 and/or RTCA DO-160

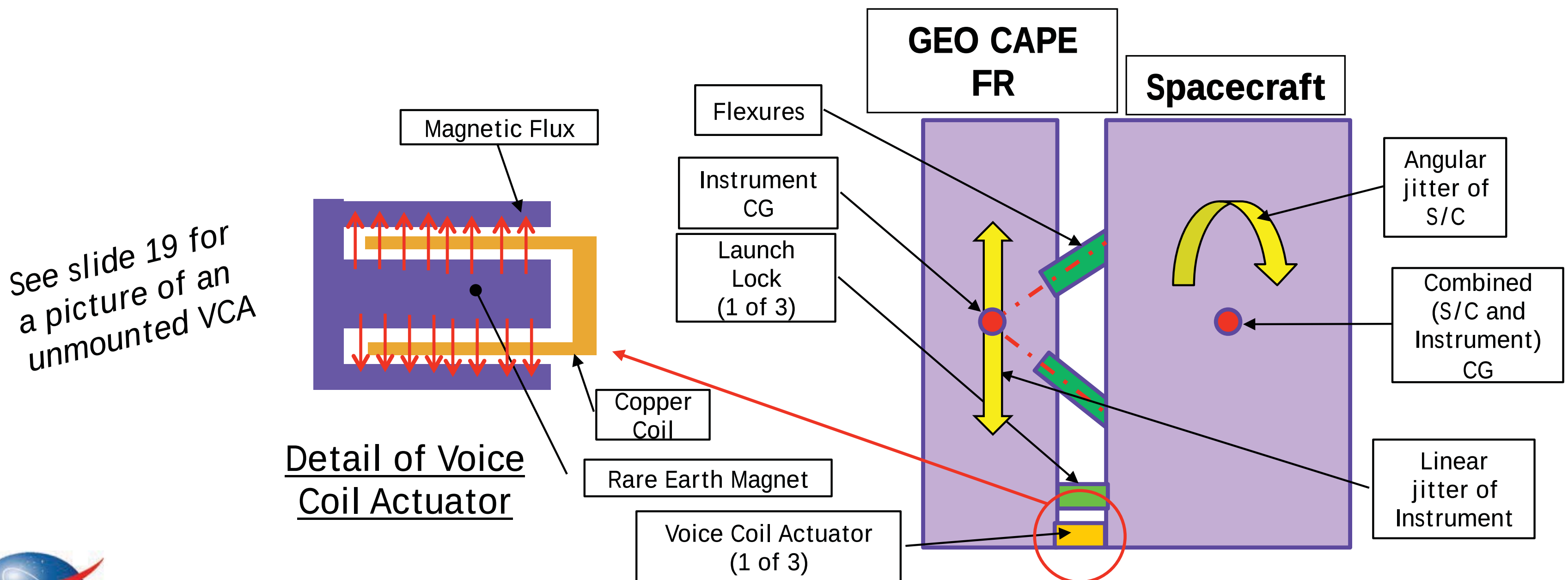
Kavlico is a leading North American and European manufacturer of OEM and off-the-shelf pressure, position (LVDT & RVDT), force, and other specialty sensors and transducers for the Transportation (including Automotive and On & Off-highway), Industrial (including HVAC, medical, wastewater, process control and other general industry applications) and Aerospace & Defense markets worldwide.

Me4: Jitter Suppression/Roll Correction System 1/9

- **Primary Requirements:**
  - Jitter rejection: GeoCape FR is attached to a geosynchronous communications spacecraft; these are known to have higher levels of angular pointing jitter than optical instruments can accommodate. Therefore, GeoCape FR must attenuate the angular motion imposed on it by the host spacecraft.
- **Discussion:**
  - This high BW (bandwidth) angular jitter could be removed by active, high BW mirror servos, but a passive approach is recommended: By angularly floating the instrument on flexures, the high BW jitter is removed passively, turning the high mass MOI of the instrument to our advantage, leaving only low BW jitter to be removed actively. *This approach eliminates the need for high BW sensors, actuators, and control loops.*
- **Proposed Design:**
  1. Implement a flexible suspension between the GeoCape FR instrument and the S/C:
     - Use three flexures whose action lines intersect at the CG of the instrument as shown in the following slides;
       - (The flexures will only transmit angular jitter motion to the instrument that is below the resonant frequency of the flexure stiffness/ instrument MOI)
     - Use three active, low stiffness, linear actuators (i.e., voice coil actuators) at the extremities of the instrument housing.
     - Use inertial rate sensors to measure and remove the residual low frequency pitch and yaw angular motions not removed by the flexures.
  2. Provide three launch locks:
     - Three launch locks placed at the extremities of the instrument housing are required to transmit the launch loads. Note that the flexure mounts are axially spring loaded to minimize axial loads while launch locks are engaged. See backup slide.
- **A question:** *This proposed design removes only the ANGULAR pitch and yaw jitter motion imposed by the spacecraft. Will the instrument - and all its sensors and optics – be affected by the LINEAR jitter motion also imposed by the spacecraft – and is NOT removed by this suspension?*

Me4: Jitter Suppression/Roll Correction System 2/9

- **Pitch motion of the S/C is about the Combined CG, so the motion at the CG of the GeoCape FR instrument is a combination of lateral motion and rotation - _if_ the instrument were rigidly attached to S/C.**
- **Now if we attach the instrument to the S/C through a spherical joint at the instrument CG, lateral motions are transmitted, but rotations are not -** *but lateral motion of instrument is not a problem, since it does not change the pointing attitude.*
- **A spherical joint at the instrument CG is not physically possible, but three flexural struts pointed at the instrument CG is possible, and, for small angular motions, is kinematically equivalent to a spherical joint. Rotational damping is now introduced by attaching three Voice Coil Actuators as far from the instrument CG as possible and driving them with current commands derived from pitch/yaw angular rate sensors and the roll camera.**



Me4: Jitter Suppression/Roll Correction System 3/9

- **Assuming <u>1 m dimensions and a mass of 250 kg</u> allows us to calculate the MOI of the instrument at 42 kg-m²**
- **Assuming a max flight load on each flexure of 100 lbf allows us to suggest a 0.1" diameter x 0.4" long flexure with an allowable YS of 50 ksi and a modulus of 30 x 10⁶ psi, which has a bending stiffness of 0.006 in-ozf/μrad**
- **Combining these results gives a rotational resonant frequency of 1.73 Hz for a "long" flexure (see slide 50).**

- **Power Consumption**
  - The electrical power required to actively remove angular jitter from the instrument is greatly dependent on the bandwidth and amplitude of that jitter, as well as the mass MOI of the instrument.
  - When these values are available, a power estimate can be derived; for budgetary purposes, the power will probably be under 5 watts.

3. Jitter Attenuation

3.1 estimate instrument angular resonance frequency on flexure tripod

3.1.1 instrument MOI

$mass_{instrument} := 250kg$ $L_{inst} := 1m$ $W_{inst} := 1m$ $H_{inst} := 1m$

MOI of rectangular solid

$$MOI_{inst} := \frac{mass_{instrument}}{12} \cdot \left(L_{inst}^2 + H_{inst}^2\right) \qquad I_h = \frac{1}{12} m \left(w^2 + d^2\right)$$

$MOI_{inst} = 41.667\ kgm^2$

3.1.2a Launch load on Instrument Launch Locks

$Launch\_Force_{inst} := mass_{instrument} \cdot Accel_{launch} \cdot rms\_factor$ $Launch\_Force_{inst} = 24802\ lbf$

3.1.2 max axial flight load on flexures

$Fmax := 100lbf$ $a_{max} := \frac{Fmax}{mass_{instrument}}$ $a_{max} = 0.181\ g$ ***surely the comsat reboost thrusters cannot exceed this..***

3.1.3 angular stiffness of flexures

assume an axially loaded cylindrical bar with a Yield Strength of $YS_{bar} := 50000psi$

$dia_{bar} := 0.1in$ $area_{bar} := \frac{\pi}{4} \cdot dia_{bar}^2$ $area_{bar} = 7.854 \times 10^{-3}\ in^2$

this bar can support an axial load of: $Load_{bar} := YS_{bar} \cdot area_{bar}$ $Load_{bar} = 392.699\ lbf$

$Length_{bar} := 0.4in$

The area MOI of the flexure is $I_{bar} := \frac{\pi}{4} \cdot \left(\frac{dia_{bar}}{2}\right)^4$ $I_{bar} = 4.909 \times 10^{-6}\ in^4$ $E_{bar} := 30000000psi$

for a beam of stiffness EI, a moment M will bend the beam into a segment of a circle of radius ρ $M = \frac{E \cdot I}{\rho}$ (1)

Solving (1) for ρ, we have $\rho = \frac{E \cdot I}{M}$ (2)

Now the deflection angle θ created in a beam of length L by moment M is given by $\theta = \frac{L}{\rho}$ (3)

Substituting (2) into (3), we have $\theta = \frac{L}{\frac{E \cdot I}{M}}$ (4)

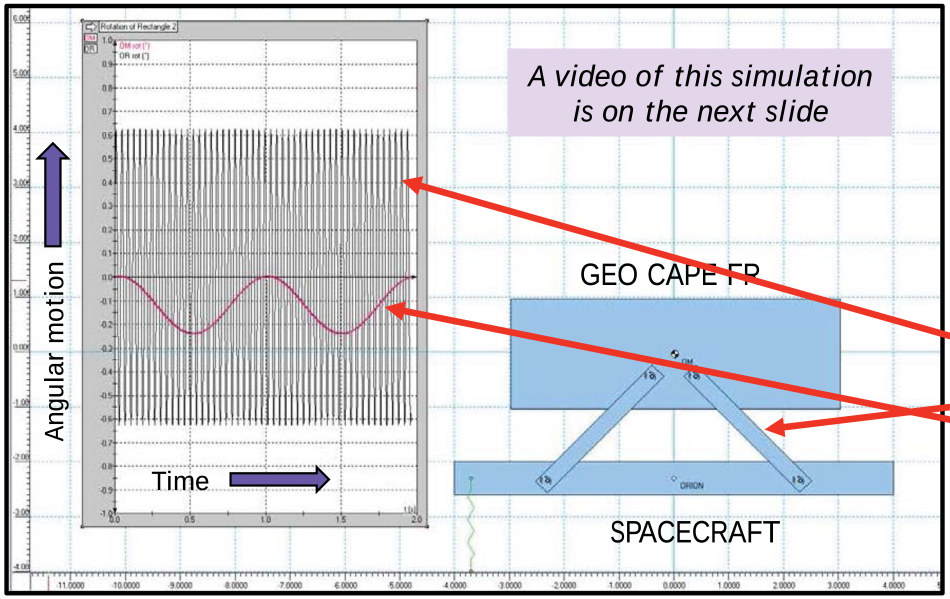
Noting that M/θ is the bending spring rate K, we can say $K_{bar} := \frac{E_{bar} \cdot I_{bar}}{Length_{bar}}$ (5) $K_{bar} = 5.89 \times 10^{-3}\ \frac{in \cdot ozf}{microrad}$

3.1.4 Resonant frequency of instrument mounted on a tripod of three flexures

$\sqrt{\frac{3 \cdot \ \ bar}{MOI_{inst}}}$

Me4: Simulated 2D performance of a notional passive isolator 4/9

- **By creating a simplified 2D mechanism model in WM2D*, it is possible to animate the expected motion of a notional passive angular jitter attenuation technique.**



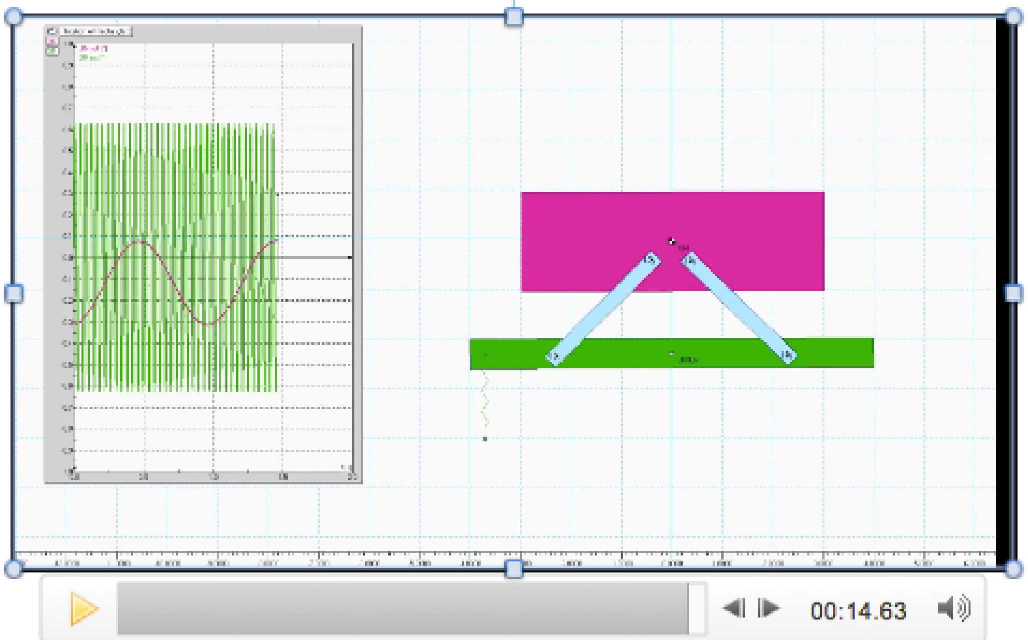
- **Two dual flexures attach GEO CAPE FR to the spacecraft - see slide 49:**
  - Let each flexure stiffness be 10 N-m/°, for an effective κ of more than 20 N-m/°
  - Assume GEO CAPE FR MOI = 40 kg-m^2`
  - Then the pitch resonant frequency = 0.85 Hz
- **Now we impose an angular motion on the spacecraft:**
  - the spacecraft is pivoted and given an initial angular velocity;
  - A linear spring from ground to the spacecraft causes an angular oscillation of the spacecraft at ~25 Hz.
- **The result:**
  - While the spacecraft oscillates at 25 Hz with an amplitude of ~±0.6°…
  - …this motion is transmitted to GEO CAPE FR through these flexures,…
  - …GEO CAPE FR would oscillate at 0.85 Hz with an amplitude of ~±0.24° (the 0.85 Hz is the resonant frequency of the flexure stiffnesses and the GEO CAPE FR MOI)
- **So GEO CAPE FR is now required to compensate for a 0.85 Hz disturbance, rather than the 25 Hz disturbance of the spacecraft.**
  - Note that no damping is included here; in an actual implementation, damping would reduce the 0.85 Hz amplitude.

- **WM2D = Working Model 2D software**

Design Simulation Technologies, Inc.
43311 Joy Road, #237
Canton, MI 48187
http://www.workingmodel.com

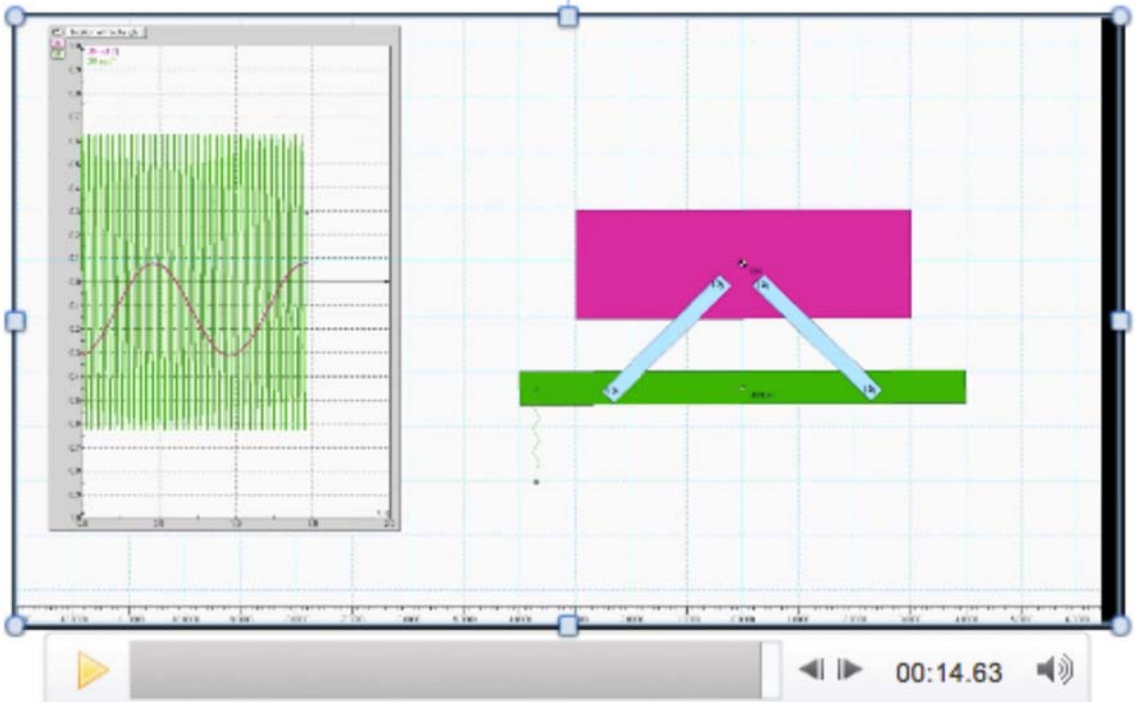
Me4: Video of 2D model of passive damper 6/9

- Click your cursor on the large black rectangle below to see the start triangle.



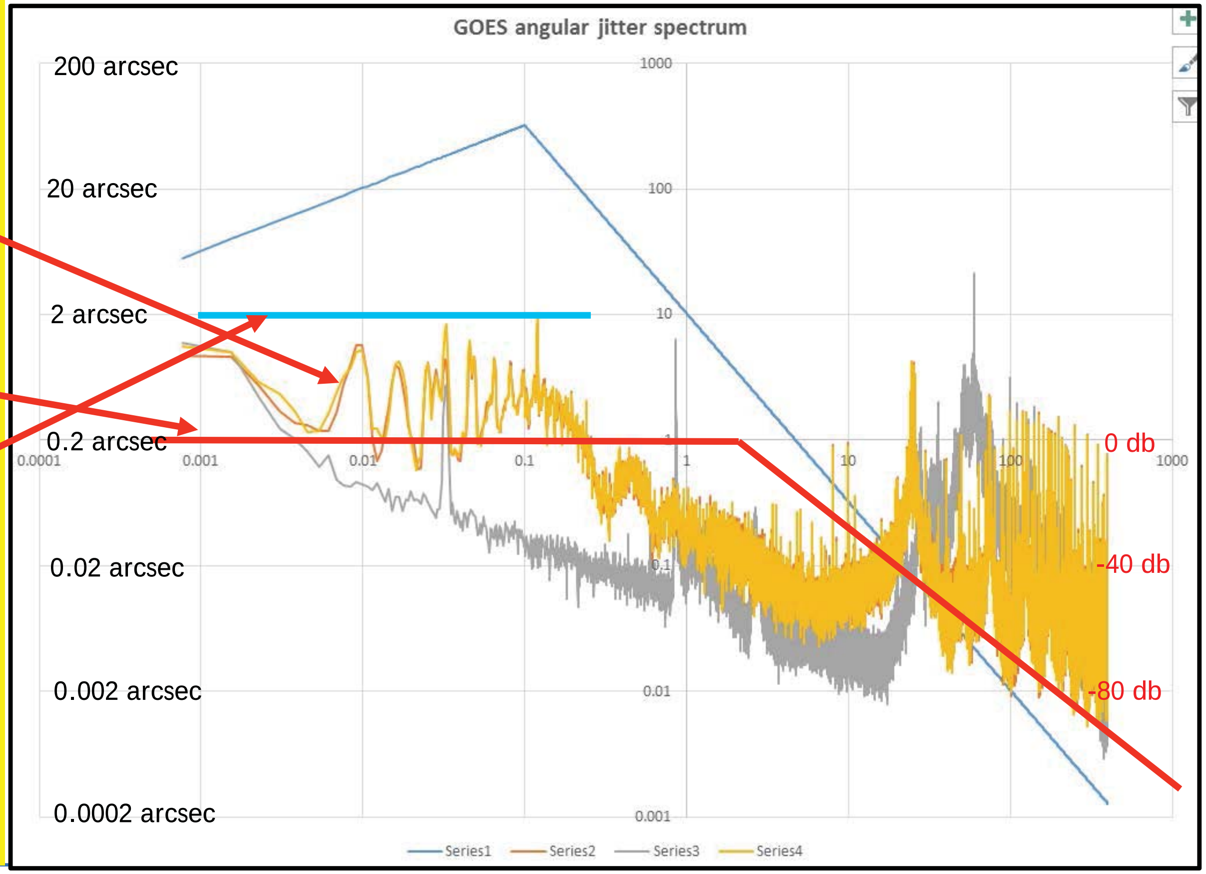
Me4: Video of 2D model of passive damper 6/9

- Click your cursor on the large black rectangle below to see the start triangle.



Me4: Transmitted Angular Jitter 6/9

- **The orange data on this plot shows the angular jitter spectrum of a typical host spacecraft.**
  - The horizontal axis is frequency in Hz; the vertical axis is RMS amplitude in microradians.
- **The -40 db/decade attenuation of the passive flexure suspension is shown as the red line; the estimated corner frequency is 1.73 Hz.**
  - If the red line is multiplied by the orange data, the result is the transmitted angular jitter RMS amplitude vs. frequency.
- **With no attenuation below 1.73 Hz, the actuators must reduce the low frequency jitter to less than 0.1 arcsec, the required pointing accuracy.**
- **This low frequency jitter appears to be under 10 microradians (2 arcsec) RMS* between 0.001 Hz and 0.2 Hz as shown by the blue line. (*with higher peaks)**
- **With angular rate sampled at 15 Hz, we can achieve an active BW of about 3 Hz, which overlaps the 1.73 Hz passive BW.**



Me4: VCA Angular motion limits 7/9

- **In this design, the coils of all three voice coil actuators are hard mounted to the instrument, and the magnet assemblies are hard mounted to the spacecraft.**
- **So, when the instrument rotates about its CG, the actuator coils will move in all directions; specifically, each actuator will move radially as well as axially.**
- **The actuator coils can move ±0.125” axially, but, due to their small radial clearance, they are limited to a radial motion of ±0.018”. This limited radial clearance would limit the angular motion of the instrument:**

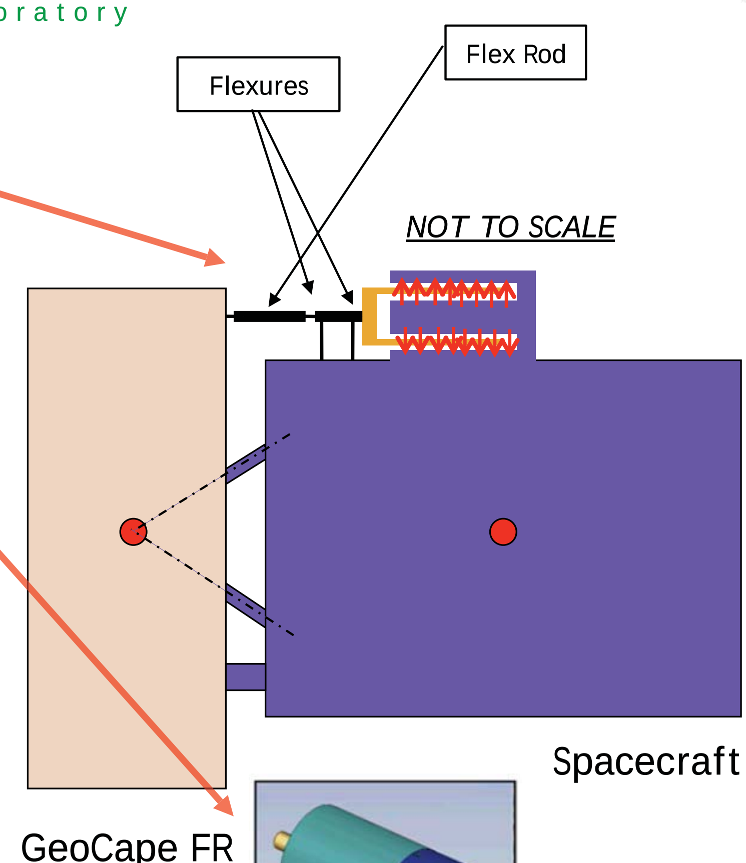
Jitter and roll rotations of GEO CAPE 2 FR instrument				
Coil to magnet clearance		0.018	inches each side	
Axis of Rotation	**radius of actuator, in**	**Allowable radial angular motion before contact, ± deg**		
X	**30**	0.034		
Y	**30**	0.034		
Z (Roll)	**30**	0.034		

This is an active Excel spreadsheet; double click and update the values as they are available.

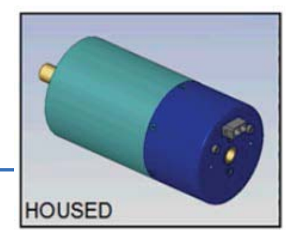
- **With stock actuators, the radial clearance is made small to maximize actuator performance.**
- **But the maximum roll error of 0.1° will cause contact within the X & Y actuators (not the roll actuator, its stroke is 750mm (30”) x ±0.1° = ±0.052”, less than its capability of ±0.125”).**
- **So, our options are:**
  - **Use X and Y VCAs with a larger radial clearance; or**
  - **Restrain the X and Y coils to linear motion within their magnets; see next slide.**

Me4: Increasing the VCA Angular motion limits 8/9

- **To increase the allowable angular motion limits of the instrument, we can maintain the alignment between a VCA coil and its magnet by adding two flexures and a flex rod to the VCA; the flexures limit the VCA output to linear motion; the rod transmits that linear motion to the instrument. Housed VCAs are also available…**



<u>"Linear Voice Coil Actuators - Housed</u>
"Housed VCAs models have been designed to simplify the use of linear voice coil actuators. With <u>internal linear bearings</u> the <u>housed actuator design</u> captures the coil assembly mechanically to keep it concentric within the field assembly as well as limiting the axial travel on both ends of the stroke."



…but without knowing the friction and durability of these <u>linear bearings</u>, we should insist on the use of frictionless, high reliability flexures.

Me4: Jitter Suppression/Roll Correction System 9/9

- **Roll Control Requirement:**
  - The estimated RMS amplitude of the spacecraft roll error is 0.1°, with a bandwidth of 0.1 Hz.
  - Optics principles require that the entire instrument be rolled to remove this error; moving individual optics elements will not work.
- **Proposed Design**
  - All of this error will have to be removed by the roll axis jitter attenuation actuator, as the resonant frequency of the flexure/instrument combination is far higher than 0.1 Hz.
  - The estimated torque required to rotate the instrument line of sight by 0.1° is 31 in-ozf.
  - Assuming the roll actuator acts at a radius of 1m, the force is 0.78 ozf and the power is 1.4 milliwatts.
  - A single roll actuator would need to be at the elevation of the CG to avoid crosstalk, but if two roll actuators are provided under the optical bench, a pure moment is exerted and there is no crosstalk.

3.5 Roll Control

Assume the jitter actuators have a radius of action of $r_{actuator} := 1m$

and a torque gain of $Force\_Gain_{VCA} := 1.31 \frac{lbf}{\sqrt{W}}$

Assume a roll angle of $\Delta\theta_{roll} := 0.1deg$

so the torque required is $Torque_{roll} := 3 \cdot K_{bar} \cdot \Delta\theta_{roll}$ $\quad Torque_{roll} = 30.843\, in \cdot ozf$

So the roll actuator must exert a force $Force_{roll} := \frac{Torque_{roll}}{r_{actuator}}$ $\quad Force_{roll} = 0.783\, ozf$

The roll power required is $P_{VCA} := \left(\frac{Force_{roll}}{Force\_Gain_{VCA}}\right)^2$ $\quad P_{VCA} = 1.397 \times 10^{-3} W$

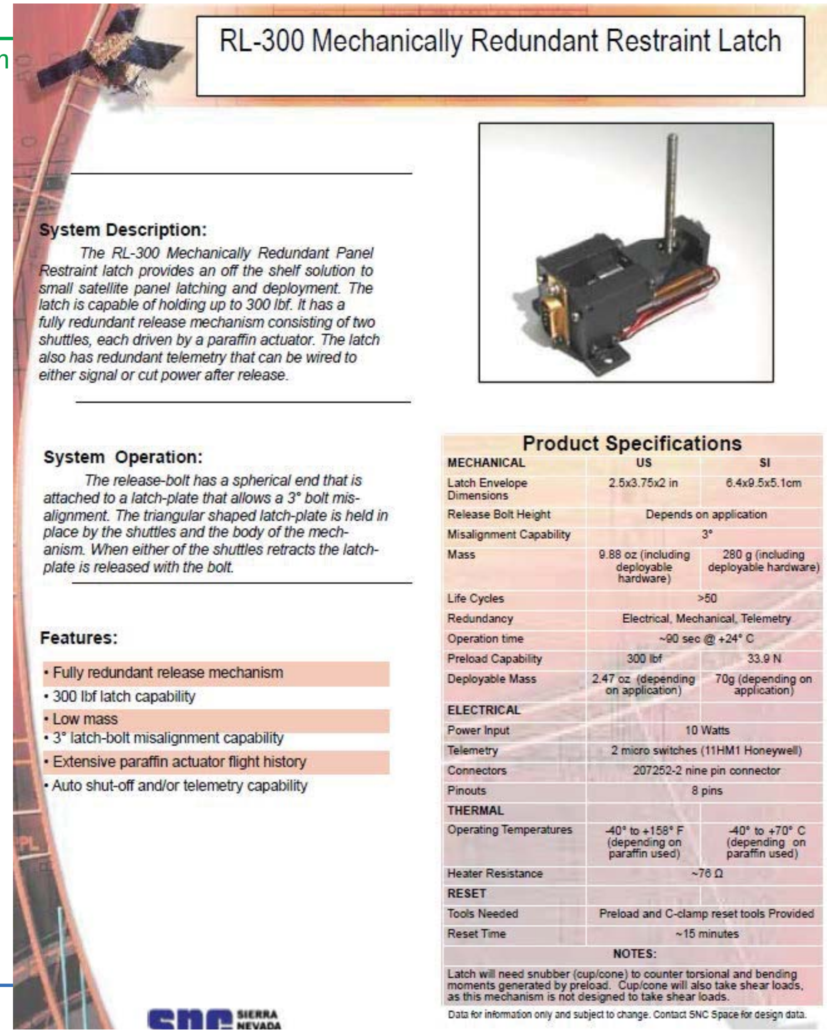
Me5: Contamination Door

- **Primary Requirements:**
  - Protect the optics from ground contamination and host spacecraft contamination
  - Dry N2 purge requires a close fitting labyrinth seal to minimize purge flow rate
  - Diameter: 521mm
- **Proposed Design:**
  - Instrument contamination doors have flown many times; common features are:

1. A door rotating on redundant sliding surface bearings.
2. Labyrinth seal at outer edge of door.
3. A latch with redundant HOP (High Output Paraffin) actuators.
4. Kickoff springs to establish the deployment angular rate.
5. Torsion springs to maintain that rate against friction torques and restrain the door against on-orbit moments.
6. A travel stop with energy absorbing material to reduce the impact loads at the end of travel.

Me5: Door Latch: HOP Latch

- **HOP Power input: 10 Watts**
- **HOP Operating Time: 90 sec at +24C**
- **HOP Operating Temp Range: -40C to +70C**
- **HOP Survival Temp Range: -40C to +70C**
- **Note max temp is limited by self-actuation***
  - * Paraffin melting temperature



RL-300 Mechanically Redundant Restraint Latch

System Description:

The RL-300 Mechanically Redundant Panel Restraint latch provides an off the shelf solution to small satellite panel latching and deployment. The latch is capable of holding up to 300 lbf. It has a fully redundant release mechanism consisting of two shuttles, each driven by a paraffin actuator. The latch also has redundant telemetry that can be wired to either signal or cut power after release.

System Operation:

The release-bolt has a spherical end that is attached to a latch-plate that allows a 3° bolt mis-alignment. The triangular shaped latch-plate is held in place by the shuttles and the body of the mech-anism. When either of the shuttles retracts the latch-plate is released with the bolt.

Features:

- Fully redundant release mechanism
- 300 lbf latch capability
- Low mass
- 3° latch-bolt misalignment capability
- Extensive paraffin actuator flight history
- Auto shut-off and/or telemetry capability

Product Specifications

MECHANICAL	US	SI
Latch Envelope Dimensions	2.5x3.75x2 in	6.4x9.5x5.1cm
Release Bolt Height	Depends on application	
Misalignment Capability	3°	
Mass	9.88 oz (including deployable hardware)	280 g (including deployable hardware)
Life Cycles	>50	
Redundancy	Electrical, Mechanical, Telemetry	
Operation time	~90 sec @ +24° C	
Preload Capability	300 lbf	33.9 N
Deployable Mass	2.47 oz (depending on application)	70g (depending on application)
ELECTRICAL		
Power Input	10 Watts	
Telemetry	2 micro switches (11HM1 Honeywell)	
Connectors	207252-2 nine pin connector	
Pinouts	8 pins	
THERMAL		
Operating Temperatures	-40° to +158° F (depending on paraffin used)	-40° to +70° C (depending on paraffin used)
Heater Resistance	~76 Ω	
RESET		
Tools Needed	Preload and C-clamp reset tools Provided	
Reset Time	~15 minutes	

NOTES:

Latch will need snubber (cup/cone) to counter torsional and bending moments generated by preload. Cup/cone will also take shear loads, as this mechanism is not designed to take shear loads.

Data for information only and subject to change. Contact SNC Space for design data.

SNC SIERRA NEVADA

Me6: Filter Wheel Assembly 1/6

- **Primary Requirements:**
  - 50 filters
  - Filter size: Fused silica, 80mm dia x 6mm thick
  - Filter change time: *as fast as possible*
  - Position accuracy: ±0.5° (±1mm at 90mm radius)
- **Derived Parameters:**
  - Filter mass: 66 gm
  - Required life: 6.1 million revolutions in 3 years

Scan Dynamics:

Move Me2: Scan Mirror 0.4° in **0.16 sec**, then hold for (50 x 2 sec =) **100 sec** total stare time + (0.2 sec x 50 =) **10 sec** total filter index time, then repeat every **110.16** sec.

5 Filter Wheel $dia_{filter} := 80mm$ $thickness_{filter} := 6mm$

5.1 Filter Mass & MOI

$volume_{filter} := \frac{\pi}{4} \cdot dia_{filter}^2 \cdot thickness_{filter}$ $volume_{filter} = 30.159289\, cm^3$

$mass_{filter} := \rho_{fusedSi} \cdot volume_{filter}$ $mass_{filter} = 0.066\, kg$

5.6 Filter Wheel Life

The mission lifetime i $T_{life} := 3yr$

the duty cycle of the instrument is $on\_time_{inst} := \frac{17hr}{day}$ $on\_time_{inst} = 70.833\%$

The filter wheel indexes 60 times every 110 sec for 17 hr/da for 3 years $freq_{FW} := \frac{60}{110sec}$ $freq_{FW} = 0.545 Hz$

but one index is 1/6th of a revolution

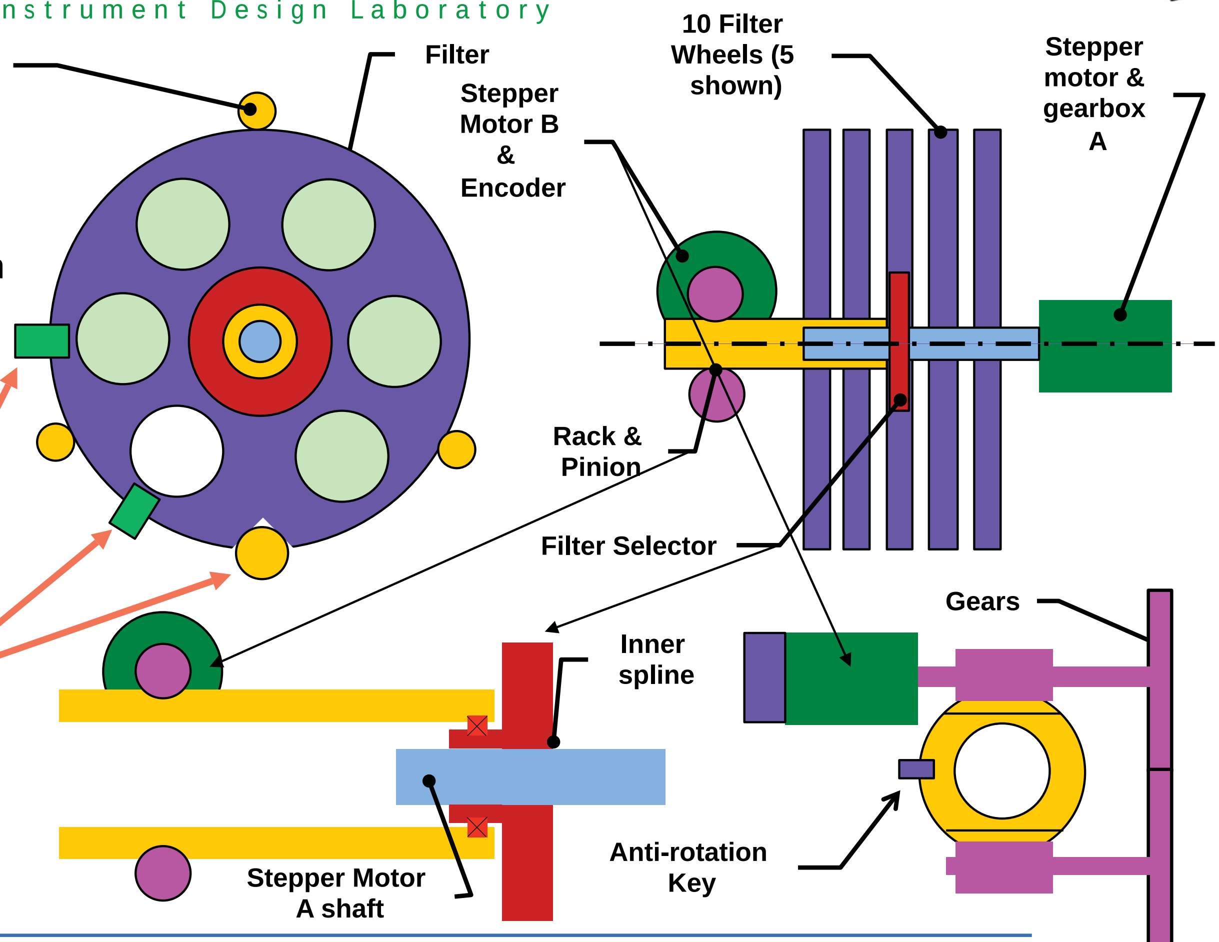
$number\_cycles\_over\_mission := T_{life} \cdot on\_time_{inst} \cdot freq_{FW} \cdot \frac{1}{6}$

$number\_cycles\_over\_mission = 6.1 \times 10^6$

Me6: Filter Wheel Assembly 2/6

Integrated Design Capability / Instrument Design Laboratory

- **Proposed Design:**
  - Ten 300 mm diameter Filter Wheels are each supported by 3 Delrin outer race V guide bearings (see Me1) on periphery.
  - Each Wheel has five 80mm Filters and one open position, all at a radius of 90mm, and can be indexed to 6 positions at 60°.
  - Inner diameter of each Wheel has a female spline (see slide 62) which mates with OD spline of Filter Selector.
  - Filter Selector is moved axially into selected Wheel by dual rack & pinion drive rotated by Stepper Motor B. Axial position is read by encoder or dead reckoned from axial travel stop.
  - Filter Selector, rotated by smaller spline on shaft of Stepper Motor A, rotates desired Filter into optical path.
  - Two optical photointerruptor switches for each Wheel indicate home and each filter positions.
  - One spring detent at each Wheel rim holds each position.

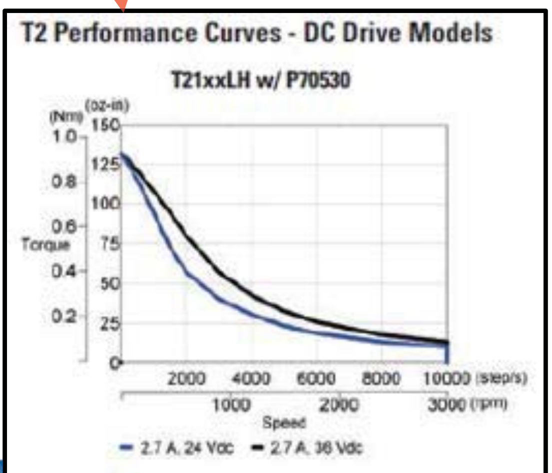


Me6: Rotating the filter wheel 3/6

- **There are several method of rotating the wheels, from slow and simple to fastest and most complex:**
  - Slow and simple: open loop stepper motor in full step mode – can be turned off when wheel is stationary. Limited MOI range due to torsional resonance.
  - Faster and more complex: open loop stepper motor in micro-stepping mode - can be turned off at cardinal step positions when wheel is stationary. Less limited MOI range.
  - Fastest and most complex: closed loop brushless DC motor with encoder position feedback and PID controller – cannot be turned off. Unlimited MOI capability.
- **We need to select the simplest/least costly method that is consistent with keeping the filter index time to a small fraction of the minimum stare/readout time of 0.5 second.**
- **For the MOI of the filter wheel, the *estimated* index times and relative complexity for each method are:**
  - Slow and simple: 0.20 sec / 1X complexity
  - Fastest and most complex: 0.01 sec / 4X complexity

Me6: Selecting the motor (no gearbox)... 4/6

- To move the Filter Wheel in 0.4 seconds, we need a torque of 62 in-ozf.
- The maximum angular velocity reached after 0.2 sec is 167 steps/sec.
- A Kollmorgen type T21xxLH DC stepper motor has a low speed output torque of >125 in-ozf, and about the same torque at 167 steps/sec.



5.3 Filter Wheel Indexing

After each stare, the Filter Wheel (FW) steps 60 deg $\theta_{FW} := 60\,\mathrm{deg}$

Assume a constant torque to move halfway, then constant negative torque to stop the motion

Assume time of half step acceleration $t_{FWhalf\_step} := 0.2\,\mathrm{sec}$ $\qquad \theta = \frac{1}{2} \cdot \alpha \cdot t^2$

$\alpha_{FW} := 2 \cdot \frac{\frac{\theta_{FW}}{2}}{(t_{FWhalf\_step})^2} \qquad \alpha_{FW} = 1.5 \times 10^3 \frac{\mathrm{deg}}{\mathrm{sec}^2} \qquad \alpha = 2 \cdot \frac{\theta}{t^2}$

$torque_{FW} := MOI_{wheel} \cdot \alpha_{FW} \qquad torque_{FW} = 0.437\,\mathrm{N} \cdot \mathrm{m} \qquad torque_{FW} = 61.945\,\mathrm{in} \cdot \mathrm{ozf}$

After 0.2 sec, the angular velocity is $\omega_{max} := \alpha_{FW} \cdot t_{FWhalf\_step} \qquad \omega_{max} = 300 \frac{\mathrm{deg}}{\mathrm{sec}}$

$step\_size := 1.8\,\mathrm{deg}$

$step\_rate\_at\_max\_vel := \frac{\omega_{max}}{step\_size} \qquad step\_rate\_at\_max\_vel = 166.667\,\mathrm{Hz}$

Me6: ...But we need a gearbox on the motor 5/6

- The holding torque of this motor is 180 in-ozf.
- If the motor were directly attached to the filter wheel, the resonant frequency of the motor would be 9.8 Hz.
- Our maximum step rate must be kept under this frequency - which we cannot do, as the indexing time would greatly increase.
- So we need to increase this frequency. The normal method of raising this frequency is to introduce a gearbox between the motor shaft and the filter wheel; the frequency increases by the square of the gearbox ratio.
- Since we would like to have a resonance of at least 200 Hz, we need a gear ratio of 4.5:1
- The step rate will increase to 750 Hz, and the max delivered torque to 4.5 x 100 = 450 ozf-in. This torque can be used to decrease the filter indexing time, limited by allowable stresses and instrument disturbance torques.

5.4 Resonant frequency

The resonant frequency of the wheel/motor is

$$f = ((\pi/2)(h/S)/\mu)^{0.5}/2\pi = (h/(8\pi\mu S))^{0.5}$$

the holding torque of the Kollmorgen T21xxLH motor is $T_{holding} := 180 ozf \cdot in$

Using our terminology:

$$f_{res} := \sqrt{\frac{T_{holding}}{8 \cdot \pi \cdot MOI_{wheel} \cdot step\_size}} \qquad f_{res} = 9.816\,Hz$$

$$ratio\_needed := \sqrt{\frac{200Hz}{f_{res}}} \qquad ratio\_needed = 4.514$$

so the max step rate would be

$$max\_step\_rate\_with\_gearbox = step\_rate\_at\_max\_vel \cdot ratio\_needed$$

$$max\_step\_rate\_with\_gearbox = 752.32\,Hz$$

Filter Wheel indexing performance with gearbox 6/6

With a gearbox ratio of 4.5:1,
the Wheel can move 30° in 0.1 sec.
(and another 30° in another 0.1 sec,
For a total Wheel motion of 60° in 0.2 sec)

The required motor torque is 55 in-ozf,

The motor step size is 1.8°
So its max step rate is 1500Hz.
At that speed, the required torque is slightly less than its estimated capability of 60 in-ozf.

The power consumption of a stepper motor does not vary with its output torque. The peak power is 64.8 W.

With an average stare time of 2 sec,
the average power is 6.5 W.

5.3 Filter Wheel Indexing

After each stare, the Filter Wheel (FW) steps 60 deg $\theta_{FW} := 60deg$

use a gearbox between the step motor and the filter wheel with a rati $N_{gearbox} := 4.5$

Assume a constant torque to move halfway, then constant negative torque to stop the motio

Assume time of half step acceleration $t_{FWhalf\_step} := 0.1sec$ $\theta = \frac{1}{2} \cdot \alpha \cdot t^2$

$\alpha_{FW} := 2 \cdot \frac{\frac{\theta_{FW}}{2}}{(t_{FWhalf\_step})^2}$ $\alpha_{FW} = 6 \times 10^3 \frac{deg}{sec^2}$ $\alpha = 2 \cdot \frac{\theta}{t^2}$

The torque applied to the Wheel is $torque_{FW} := MOI_{wheel} \cdot \alpha_{FW}$ $torque_{FW} = 247.78 in \cdot ozf$

The torque from the motor is $torque_{motor} := \frac{torque_{FW}}{N_{gearbox}}$ $torque_{motor} = 55.062 in \cdot ozf$

After the half step, the wheel angular velocity is $\omega_{max} := \alpha_{FW} \cdot t_{FWhalf\_step}$ $\omega_{max} = 600 \frac{deg}{sec}$

$step\_size := 1.8deg$

$step\_rate\_at\_max\_vel := \frac{\omega_{max} \cdot N_{gearbox}}{step\_size}$ $step\_rate\_at\_max\_vel = 1500Hz$

5.4 Filter Wheel Peak Power

At this step rate, the motor, driven with 24vdc at 2.7A, can exert $T_{out\_motor} := 60in \cdot ozf$

And the motor peak power is $P_{motor} := 24volt \cdot 2.7A$ $P_{motor} = 64.8W$

5.5 Filter Wheel Average Power

With an average stare time of $t_{stare\_avg} := 2sec$

andan indextime of $t_{wheel\_index} := 2 \cdot t_{FWhalf\_step}$ $t_{wheel\_index} = 0.2s$

The average power is $P_{avg\_FW} := P_{motor} \cdot \frac{t_{wheel\_index}}{t_{stare\_avg}}$ $P_{avg\_FW} = 6.48W$

Conclusions and Concerns

- **Conclusions**

– Me1: Diffuser Wheel	low risk, but it is quite large…
– Me2: Scan Mirror	low risk; launch locks should not be needed if mirror is balanced.
– Me3: Fast Steering Mirror	low risk.
– Me4: Jitter/Roll Suppression	needs development due to new concept of passive low pass mechanical rotation filter; the roll actuator must rotate the entire instrument to remove roll error, but instrument inertia helps.
– Me5: Contamination Door	low risk.
– Me6: Filter Wheel Assembly standard machine	design must support high duty cycle and many life cycles; mechanism is combination of elements (splines, gears, stepper motors)

- **Concerns**

– **Me4: This proposed design removes only the ANGULAR jitter motion imposed by the spacecraft. Will the instrument - and all its sensors and optics – be affected by the LINEAR jitter motion also imposed by the spacecraft – and is NOT removed by this suspension?**

Future Work

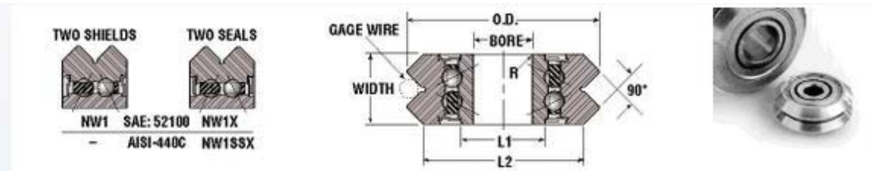
- Most of the mechanisms described here have been used many times; the exception is Me4, the active jitter suppression system.
- More specifically, the use of flexures to passively reject high frequency angular jitter is a new concept, and needs further analysis and prototype testing to verify its viability.
- However, since the concept does not involve any technological breakthroughs, but only requires the proper use of basic rigid body mechanics, the analysis and testing efforts should be straightforward.

Backup Slides

- **Me1 backup:**
  - V groove ball bearing
- **Me2 backup:**
  - Renishaw Encoder (2 slides)
- **Me3 backup**
  - Voice Coil Actuator Specs
  - LVDTs vs. DITs
- **Me4 backup:**
  - Development of Jitter Mount Concept (4)
  - Flexure Assembly Detail
  - Effect of flexure length
  - A flexure mount that creates motion clearance
- **Me6/7 backup**
  - Discussion of 100 filter mechanisms concepts
  - Stepper motor slides

Me1: Dual race V groove bearings

- Chart from http://www.nationalprecision.com/ball-bearings/guide-wheel_v-groove_bushings.php
- Lubrication notes (not shown): http://www.pbclinear.com/Download/WhitePaper/Lubrication-for-Linear-Roller-Bearings-and-Raceways.pdf



V GROOVE GUIDE WHEEL BEARINGS

NPB Part No. RFQ per item	Industry Part No.	Bore +.0000 -.0003	O.D. +/-.005	Width +.0000 -.0050	L1 Ref.	L2 Ref.	R Will Clear Radius	Gage Wire Diam.	Dynamic Radial Load Lbs. Based on avg. life of 2500 hours				Thrust Load Lbs.	Static Radial Load Lbs.
									33.3 RPM	100 RPM	500 RPM	1000 RPM		
NW1	W1	.1875	.771	.3100	.314	.625	.012	.0937	350	245	145	112	65	245
NW1X	W1X	.1875	.771	.3100	.314	.625	.012	.0937	350	245	145	112	65	245
NW1SSX	W1SSX	1875	.771	.3100	.314	.625	.012	.0937	310	218	126	100	55	200
NW2	W2	.3750	1.210	.4375	.530	1.000	.012	.1250	734	487	288	227	122	610
NW2X	W2X	.3750	1.210	.4375	.530	1.000	.012	.1250	734	487	288	227	122	610
NW2SSX	W2SSX	.3750	1.210	.4375	.530	1.000	.012	.1250	562	390	230	183	90	455
NW3	W3	.4724	1.803	.6250	.640	1.500	.024	.1875	1338	925	543	435	535	910
NW3X	W3X	.4724	1.803	.6250	.640	1.500	.024	.1875	1338	925	543	435	535	910
NW3SSX	W3SSX	.4724	1.803	.6250	.640	1.500	.024	.1875	1070	745	434	349	428	705
NW4	W4	.5906	2.360	.7500	.878	2.000	.024	.2500	2055	1405	815	650	655	1235
NW4X	W4X	.5906	2.360	.7500	.878	2.000	.024	.2500	2055	1405	815	650	655	1235
NW4SSX	W4SSX	.5906	2.360	.7500	.878	2.000	.024	.2500	1593	1129	648	520	510	955

Guide wheel bearings are precision ground, double row, angular contact bearings. These bearings are pre-lubricated and available in either 52100 chrome or 440C stainless steel. Although the standard chrome steel version is available either sealed or shielded, the stainless steel design is available sealed only. The concentric and adjustable bushings provide a simple, effective means of adjusting the free play of the guide wheel system.

Me2: Renishaw REXA Rotary Encoder

- **Accuracy is ±1 arcsec**
- **Repeatability of ±0.01 arcsec**
- **So on-orbit mapping may be necessary to achieve ground truth accuracy to 0.1 arcsec (10% of pixel size)**

- **Encoder electronics mass**
  - Two readheads@19gm: 36 gm
  - Cable: 32 gm/m
  - Interface box: 218 gm

From http://resources.renishaw.com/en/details/data-sheet-rexa-ultra-high-accuracy-absolute-angle-encoder--44234

With zero coupling losses and exceptional repeatability, the REXA ultra-high accuracy angle encoder achieves better than ±1 arc second total installed accuracy.

Like the RESM encoder, the REXA is a stainless steel ring with the scale graduations marked axially onto the periphery, but with a number of differences to improve upon RESM's already impressive accuracy.

REXA has a thicker cross-section to ensure that the only significant installation error is eccentricity. Eccentricity is easily removed by using 2 readheads, and combining the signals inside the host controller.

The only errors remaining are graduation errors and readhead SDE, both of which are so small they are often negligible.

As a non-contact encoder, REXA offers dynamic performance advantages, eliminating coupling losses, oscillation, shaft torsion and other hysteresis errors that plague enclosed encoders.

The REXA system operates at temperatures up to +80 °C and speeds to 8 500 rev/min.

REXA total installed accuracy grades:

REXA diameter	Total installed accuracy (with 2 readheads)
⩾100 mm	±1 arc second
75 mm	±1.5 arc second
⩽57 mm	±2 arc second

- Use with two RESOLUTE™ readheads to give ultra-high accuracy
- Installed accuracy to ±1 arc second with dual readheads
- Sub-divisional error to ±0.04 arc second
- Resolutions to 0.00030 arc second
- Repeatability to 0.01 arc second
- Wide range of standard sizes from 52 mm to 417 mm
- Large internal diameter for ease of integration
- Flange mounted with easy 4-point adjustment method

Me2: Renishaw REXA Rotary Encoder

- **Ring diameter of 417mm assumed in MEL**

Ring diameter (mm)	200	206	209	229	255	300	350	417
Mass (kg)	1.35	1.43	1.49	1.68	2.02	2.73	3.59	5.09
Inertia (kg-cm²)	99	111	118	164	246	468	845	1 700

Me3: Voice Coil Actuator Specs

- **From http://www.beikimco.com/pdf/LA15-16-024%20%28LTR%29.pdf**

WINDING CONSTANTS *	UNITS	TOL	SYMBOL	WDG A	WDG B
DC RESISTANCE	OHMS	±12.5%	R	4.7	15.0
VOLTAGE @ F_P	VOLTS	NOMINAL	V_P	33.0	58.6
CURRENT @ F_P	AMPERES	NOMINAL	I_P	7.02	3.91
FORCE SENSITIVITY	LB/AMP	±10%	K_F	2.85	5.12
	N/AMP	±10%		12.68	22.77
BACK EMF CONSTANT	V/FT/SEC	±10%	K_B	3.86	6.94
	V/M/SEC	±10%		12.68	22.77
INDUCTANCE ****	MILLI-HENRY	±30%	L	1.25	4.05

ACTUATOR PARAMETERS *	UNITS	SYMBOL	VALUE
PEAK FORCE **	LB	F_P	20.0
	N		89.0
CONTINUOUS STALL FORCE ***	LB	F_{CS}	5.5
	N		24.47
ACTUATOR CONSTANT	LB/ $\sqrt{\text{WATT}}$	K_A	1.31
	N/ $\sqrt{\text{WATT}}$		5.83
ELECTRICAL TIME CONSTANT	MICRO-SEC	τ_E	270
MECHANICAL TIME CONSTANT	MILLI-SEC	τ_M	1.28
POWER I^2R @ F_P	WATTS	P_P	232
STROKE	± INCHES		0.125
	± MM		3.18
CLEARANCE ON EACH SIDE OF COIL	IN		0.018
	MM		0.46
THERMAL RESISTANCE OF COIL	°C/WATT	θ_{TH}	5.0
MAX. ALLOWABLE COIL TEMP.	°C	TEMP	155
WEIGHT OF COIL ASSEMBLY	OZ	WT_C	1.55
	G		43.94
WEIGHT OF FIELD ASSEMBLY	OZ	WT_F	6.5
	G		184.27

* 25°C AMBIENT TEMPERATURE
** 10 SECONDS AT 25°C AMBIENT & 155°C COIL TEMP
*** 25°C AMBIENT & 155°C WINDING TEMPERATURE
**** MEASURED AT 1000 Hz

Me3: LVDTs vs. DITs

- **Electronics:**
  - LVDTs can be driven by commercial chips http://www.analog.com/static/imported-files/data_sheets/AD598.pdf
    - Per LVDT: 20 pin brazed ceramic DIP: 1" x 0.29" x 0.09"
  - DITs need matched proprietary electronics:
    - Per two differential channels: : 6 oz, 2.5" x 2.3" x 1.3" electronics box.
- **Cable length and temperature:**
  - LVDTs are not sensitive
  - DITs are sensitive
- **Cable motion:**
  - LVDTs are not sensitive
  - DITs are sensitive

- "DIT" = Differential Impedance Transducer
- High impedance sensor; output affected by cable motion & temperature changes
- Two channel electronics box: 6oz x 2.5" x 2.3" x 1.3"
- Analog output
- http://www.kamansensors.com/index.html

From http://www.kamansensors.com/html_pages/tech_note_cable_length.html

"CABLE LENGTH AND SYSTEM PERFORMANCE

An eddy current, linear displacement system consists of a sensor or probe, an electronics module and an interconnecting coax cable. At the heart of the system is the impedance bridge circuit. One leg of the bridge is connected to the sensor coil via the sensor cable. The impedance of that circuit is balanced with electronic components. As a target engages the electromagnetic field generated by the sensor, the impedance of the sensor side of the bridge changes resulting in an output change in the system.

Coil vs. Cable Impedance

It is important to understand that the sensor and the interconnecting cable both provide inductance, capacitance, and resistance to that leg of the impedance bridge circuit. This circuit cannot distinguish between coil or cable induced impedance change.

System sensitivity is based on the amount of impedance change in the bridge circuit caused by target-field interaction. To maximize sensitivity, the ratio of coil impedance to cable impedance must be maximized. A simple way to do this is to keep the cable lengths as short as possible.

Cable Temperature

As impedance is a combination of inductance, capacitance, and resistance, anything that affects these properties affects impedance. Changes in the cable temperature can affect the system output.

Cable Movement

Physical movement of the cable can result in minor changes in the distance between the center conductor of the coax cable and the shield. This can result in capacitance changes in the cable that can affect the system output.

When A Long Sensor Cable Is Unavoidable

Kaman can optimize the oscillator frequency used to excite the coil allowing for a longer cable. This can be detrimental in some dynamic applications as it reduces the maximum allowable surface velocity of the target.

With longer cables, it is important to use a highly conductive target such as aluminum.

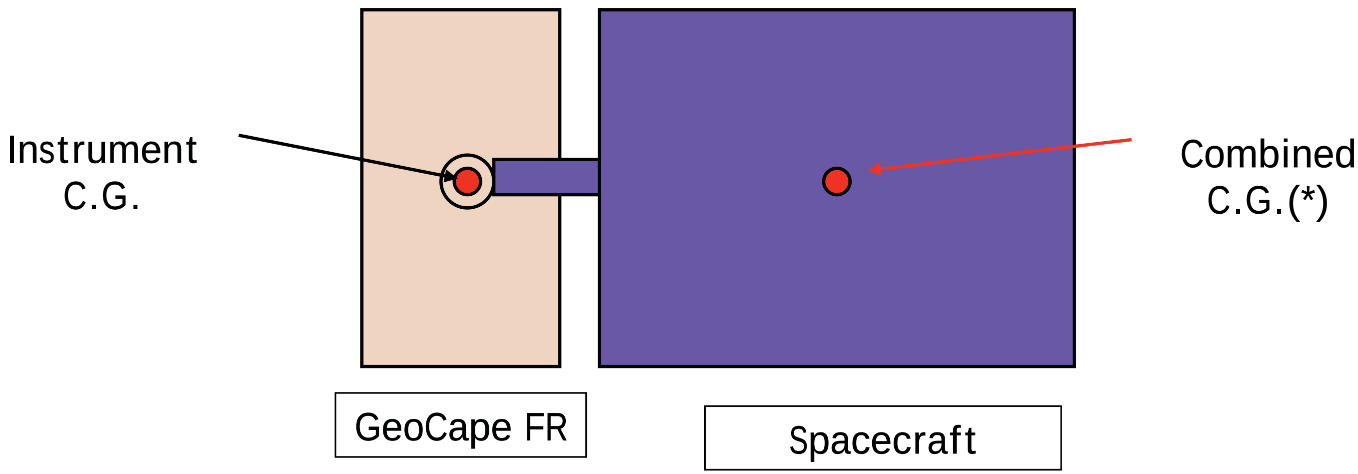
Restraining long cables to prevent vibration induced movement helps improve overall system stability.

Routing long cables to avoid temperature changes is also important to system stability. Routing the cable through conduit can help minimize temperature changes in the cable.

Cable lengths can be increased where required by the application. However, performance may be degraded and maximum cable lengths are determined by sensor and target type. Contact Kaman for application assistance.

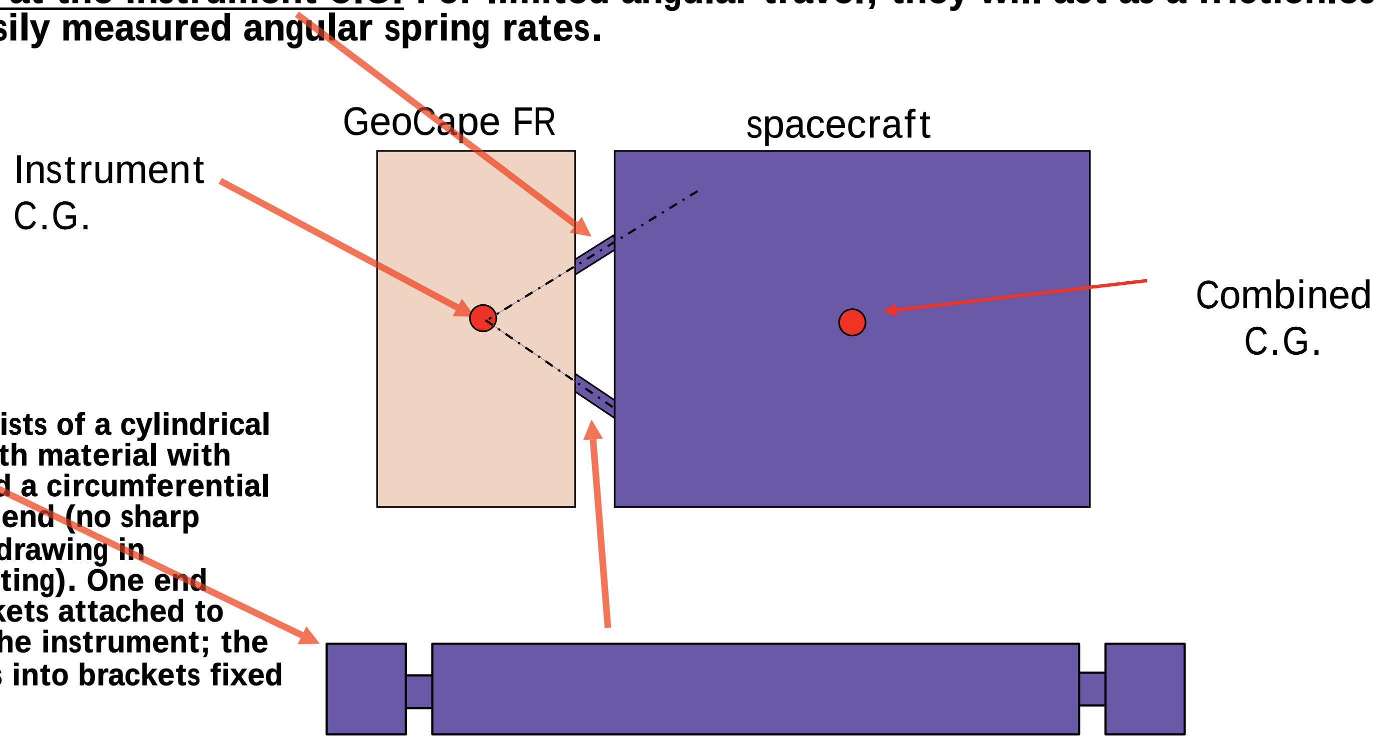
Me4: Development of Jitter Mount Concept 1/4

- **Conceptually, mount the instrument at its C.G. (Center of Gravity) with a "frictionless spherical bearing", so there are no angular moments applied to it by the angular jitter of the spacecraft. The attenuation of angular jitter is theoretically infinite at all frequencies.**
- *(*Note that the "Combined C.G." is calculated from the MOI of the spacecraft and only the md² term of the instrument MOI.)*



Me4: Development of Jitter Mount Concept 2/4

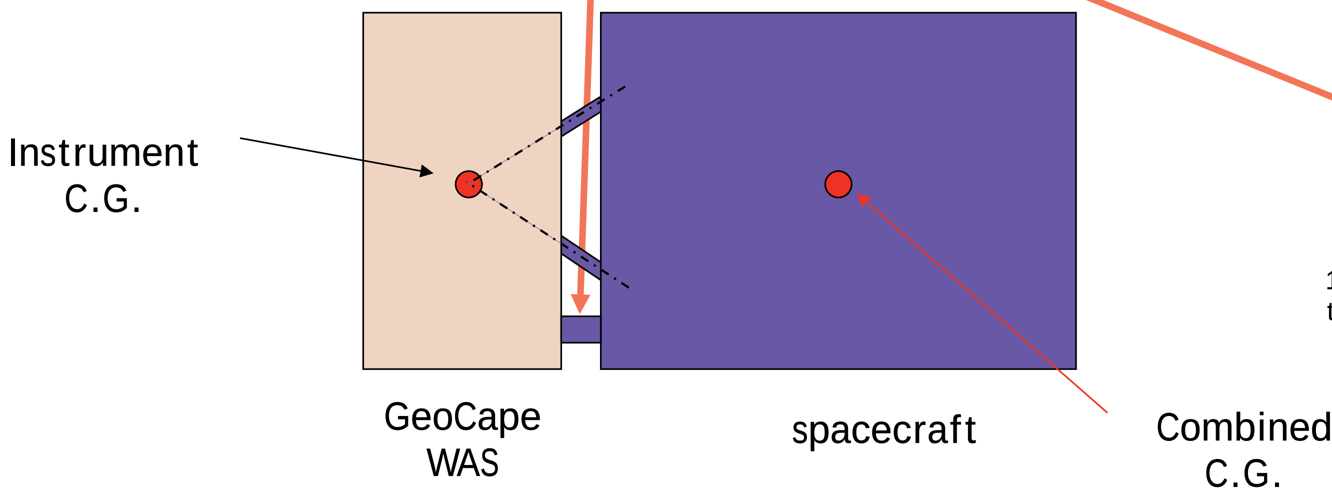
- But a frictionless spherical bearing is impossible to build, so let's replace it with <u>three flexures forming a tripod pointed at the instrument C.G.</u> For limited angular travel, they will act as a frictionless bearing with small, easily measured angular spring rates.



- Each <u>flexure</u> consists of a cylindrical bar of high strength material with threaded ends and a circumferential groove near each end (no sharp internal corners; drawing in PowerPoint is limiting). One end threads into brackets attached to strong points on the instrument; the other end threads into brackets fixed to the S/C.

Me4: Development of Jitter Mount Concept 3/4

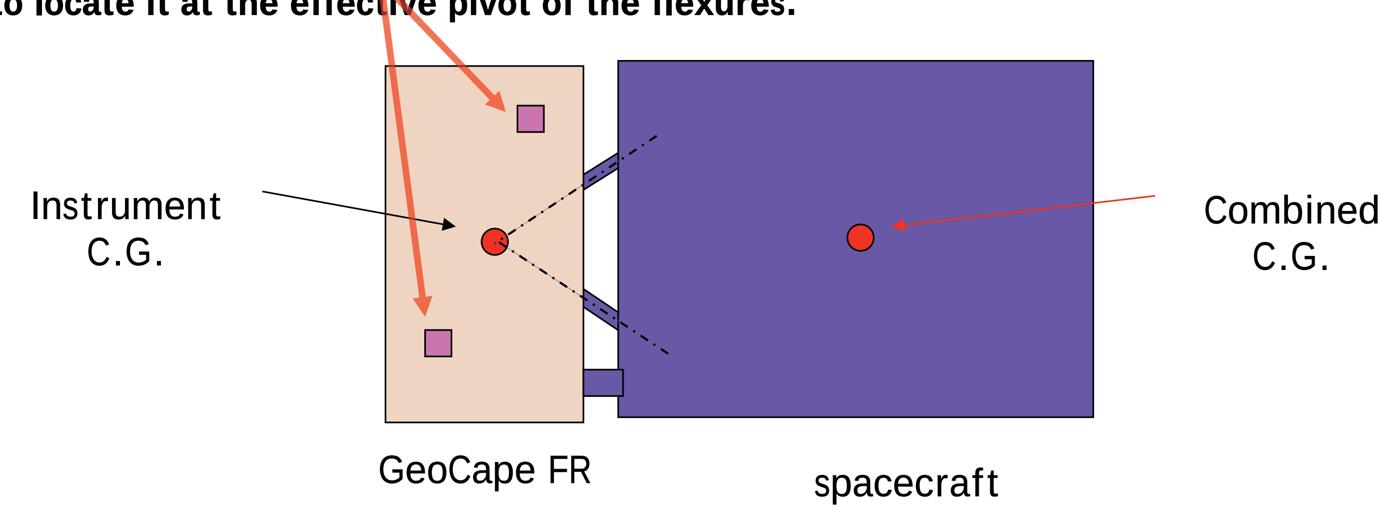
- **We will add three active linear voice coil actuators at some distance from the instrument C.G. to damp angular motions of the GeoCape FR instrument.**
- **The actuators' task will be minimal, since the flexure mounting passively removes the high frequency angular S/C jitter.**



Me4: Development of Jitter Mount Concept 4/4

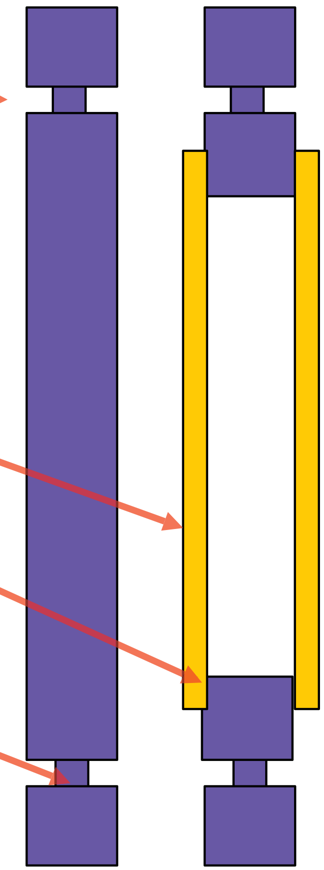
- *But how do we ensure that the effective pivot of the flexures is precisely at the C.G. of the instrument?*
- **In two steps:**

1. **Careful instrument design in a 3D modeler would place the vertex of the flexures close to the instrument C.G.**
2. **By examining the phase angle of the angular acceleration during Flight Acceptance vibration testing of the instrument, and adding <u>ballast masses</u> to adjust that acceleration to zero, the instrument C.G. is moved slightly to locate it at the effective pivot of the flexures.**



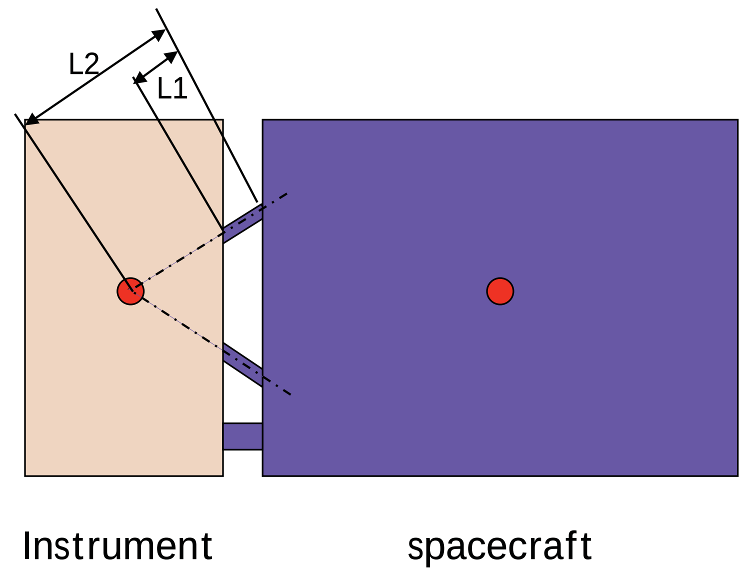
Me4: Flexure Assembly Detail

- For this application, each flexure assembly conceptually is a rigid solid bar with circumferential grooves near each end.
- In practice, most of the bar could be an aluminum tube, with a high strength flexure threaded into each end of the tube.
- The outer ends of these flexures would also be threaded to attach the fitting to the spacecraft and instrument.
- The bending spring rate “K” of each flexure is derived elsewhere as:
- K = E * I / L, where
  - E = elastic modulus,
  - I = area MOI,
  - L = length



Me4: Effect of flexure length

- **The diagram at the right defines two dimensions:**
  - L1 is the distance between the flexure grooves
  - L2 is the total distance from the spacecraft flexure groove to the CG of the instrument
- **With the 2D model shown, assume that L1 = L2 (i.e., the spacecraft flexure is at its CG):**
  - If the instrument were rotated around an axis normal to the screen, the effective torsional spring rate would be 2*K for this 2D case (for the 3D case, with 3 flexures, the rate would be 3*K), since the flexures near the spacecraft do not bend.
- **However, if L1 approaches zero (very short flexure assemblies), the effective rate increases:**
  - Now, if the instrument were rotated around an axis normal to the screen, the effective torsional spring rate would be 4*K for this 2D case (for the 3D case, with 3 flexures, the rate would be 6*K), since the flexures near the spacecraft bend just as much as the flexures near the instrument.
- *Conclusion:*
  - *The ratio L1/L2 should be as high as practical to minimize the effective bending spring rate and so reduce the instrument/flexure resonant frequency.*

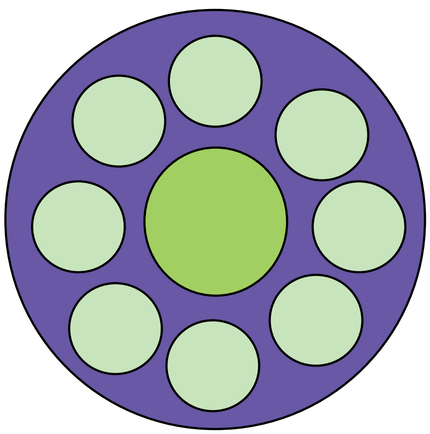


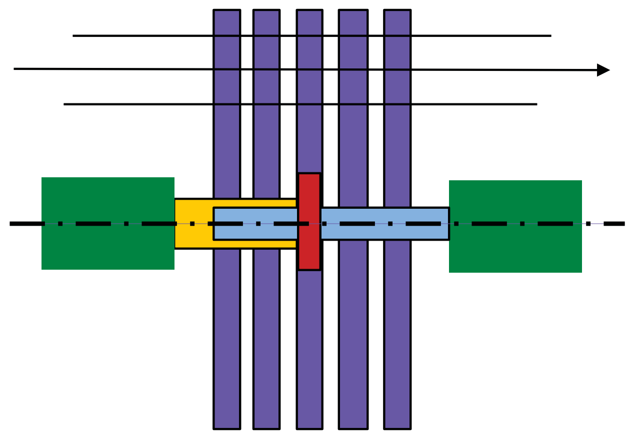
Me4: A flexure mount that creates motion clearance

- **For launch, the instrument is held by launch locks, but when the locks are released, the instrument must move away from the lock interface to have room to rotate through small angles to accommodate spacecraft jitter motion.**
- **A means to create this motion:**
  - One end of each of the 3 flexure assemblies is supported on a sliding block with limited travel.
  - The block is preloaded to the upper end of its travel by a Belleville spring.
  - During final assembly, as the instrument is pulled down into the launch locks, each flexure assembly compresses its Belleville spring.
  - On orbit, when the launch locks are released, each Belleville spring pushes its attached flexure assembly (and the instrument) up, away from the launch lock.
- **The preload on each Belleville spring is chosen to be:**
  - More than the highest axial force expected on that flexure assembly, and
  - Less than the force that would buckle the flexures.
- **Heritage**
  - The Windsat sensor built by NRL (Naval Research Lab) rotated at 30 rpm during scanning; to create the running clearance after launch lock release, the structural lower plate was elastically deformed by the launch lock forces, so when it was released, it moved away from the stationary spacecraft, giving it clearance for rotation.
- **Concern**
  - It would be highly desirable to slowly release the launch locks to avoid structural shock loads on the flexures and the instrument as the Belleville springs accelerate the instrument toward its operational position. How to achieve this low shock release needs to be thought through. Could a TiNi Frangibolt be used – not to break a bolt, but to slowly extend the flexures and push the instrument away from its launch locks?

Me6: Discussion of 100 filter mechanism concepts

- **Given the desirability of having 50 filters available, instead of just the capacity of two wheels, several possibilities come to mind:**
  - Linear magazine
  - Carousel magazine
  - Rolodex flipper
- **All of these would need handling of individual filters, which is undesirable.**
- **Using multiple stacked filter wheels driven selectively by a single stepper motor appears desirable, as it uses a minimum of components in a compact envelope. The selector for which wheel is rotated is driven by a second stepper motor that axially moves the drive element from wheel to wheel.**





Me6: Stepper motors: Microstepping

- from http://en.wikipedia.org/wiki/Stepper_motor#Microstepping
- "Microstepping
- "What is commonly referred to as microstepping is often "sine cosine microstepping" in which the winding current approximates a sinusoidal AC waveform. Sine cosine microstepping is the most common form, but other waveforms can be used. Regardless of the waveform used, as the microsteps become smaller, motor operation becomes more smooth, thereby greatly reducing resonance in any parts the motor may be connected to, as well as the motor itself. Resolution will be limited by the mechanical stiction, backlash, and other sources of error between the motor and the end device. Gear reducers may be used to increase resolution of positioning.
- "Step size repeatability is an important step motor feature and a fundamental reason for their use in positioning.
- "Example: many modern hybrid step motors are rated such that the travel of every full step (example 1.8 degrees per full step or 200 full steps per revolution) will be within 3% or 5% of the travel of every other full step, as long as the motor is operated within its specified operating ranges. Several manufacturers show that their motors can easily maintain the 3% or 5% equality of step travel size as step size is reduced from full stepping down to 1/10 stepping. Then, as the microstepping divisor number grows, step size repeatability degrades. At large step size reductions it is possible to issue many microstep commands before any motion occurs at all and then the motion can be a "jump" to a new position."

Me6: Stepper motors: Ringing and resonance

"When the motor moves a single step, it overshoots the final resting point and oscillates around this point as it comes to rest. This undesirable ringing is experienced as motor vibration and is more pronounced in unloaded motors. An unloaded or under loaded motor may, and often will, stall if the vibration experienced is enough to cause loss of synchronization.
"Stepper motors have a natural frequency of operation. When the excitation frequency matches this resonance, the ringing is more pronounced, steps may be missed, and stalling is more likely.

- **Resonant frequency of an inertial load attached to a stepper motor output shaft:**
  - Assumes the motor output torque varies sinusoidally with position

$$f = ((\pi / 2)(h / S) / \mu)^{0.5} / 2\pi = (h / (8\pi \mu S))^{0.5}$$

  - Where:

f = resonant frequency

h -- holding torque

μ -- moment of inertia of rotor and load

S -- step angle, in radians

More info is at
http://homepage.cs.uiowa.edu/~jones/step/physics.html#resonance

Me6: Stepper motors: Nomenclature

Full NEMA name

The full NEMA name of a stepper motor is written as:

"NEMA" DDMMLLL-CCCIVVVSSSW

...where the letters have the following meaning:

Letters	Value	Unit
DD	Diameter / Faceplate size	inches·10
MM	Mount type	**C**: Flange with slots; **D**: Face with tapped holes; **CD**: Face flange with holes
LLL	Length	inches·10
CCC	Phase current	amps·10
I	Insulation class	Maximum operating temperature: **A**: 221 °F (105 °C); **B**: 266 °F (130 °C); **F**: 311 °F (155 °C); **H**: 356 °F (180 °C) Class B is the most common type for 60 cycle motors in the US. Internationally Class F is the most common type for 50 cycle motors. Generally speaking, going 10 °F above the maximum temperature will reduce the motor life by half.
VVV	Phase voltage rating	voltage·10
SSS	Steps	steps per revolution
W	Winding code	How many internal wires the external wires are connected to: **A**: 2 wires; **B**: 3 wires; **C**: 4 wires; **D**: 5 wires; **E**: 6 wires; **F**: 8 wires

Me6: Kollmorgen T2 Series Stepper Motor

T2 Series Stepper Motors

General Specifications

- NEMA Size 23
- High Torque at moderate speeds
- Inch standard mounting
- CE cUR and UR compliant
- Unipolar or Bipolar windings
- Features: leadwire connection, flat or smooth shaft
- Options: MS connector, terminal boxes, encoder mounting provisions, 200 LPR, 400 LPR encoders with line drivers
- Custom Motors

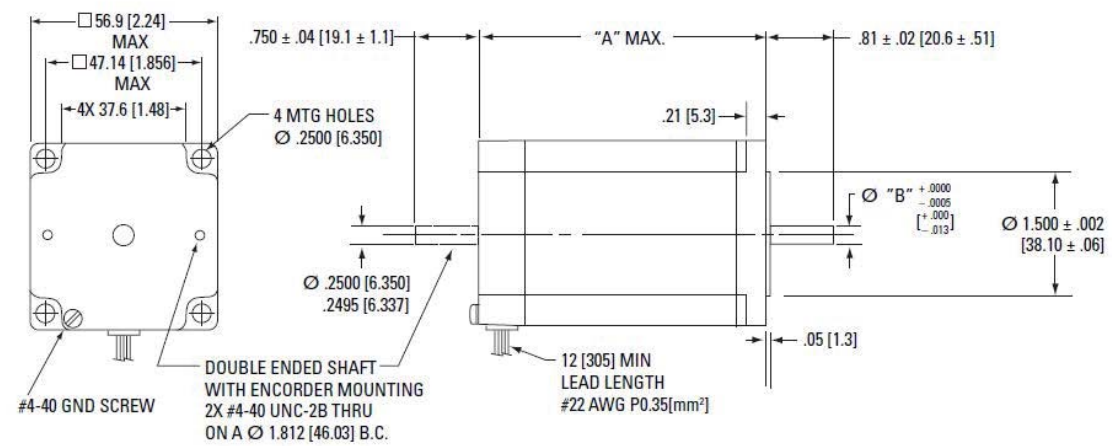
Phases	2
Full Steps per Revolution	200
Step Angle	1.8°
Step Accuracy (of one full step, no load)	± 2 %
Operating Temperature	-20°C to +40°C
Insulation Class	Class B, 130°C
Insulation Voltage Rating	340 Vdc
Insulation Resistance	100 Megohms

Me6: Kollmorgen Stepper Motor: T21 drawing

- From http://www.kollmorgen.com/en-us/products/motors/stepper/powermax-m-and-p-series/
- From: Stepper_Catalog_en-US_RevC_EN

T2 Outline Drawings

Leadwire Hookup Models



Dimensions in inches [mm]

Model	"A" Max	"B" Max
T2H	1.64 (41.6)	
T21	2.21 (56.1)	0.2500 (6.35)
T22	3.06 (77.7)	
T23	4.06 (103.1)	0.3125 (7.94)

Me6: Kollmorgen Stepper Motor: T21xxLH performance

Integrated Design Capability / Instrument Design Laboratory

T2 Performance Data

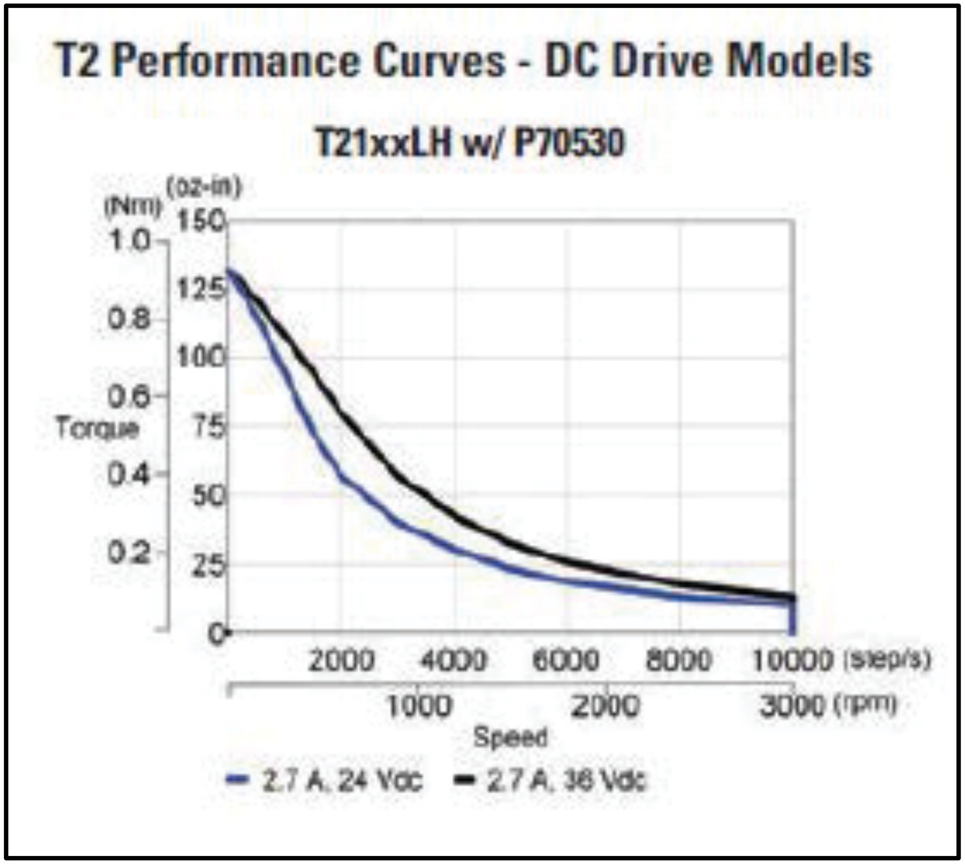
	Motor Model Number	Config.		Holding Torque (2 phases on)	Rated Current/ Phase	Phase Resistance	Phase Inductance	Detent Torque	Thermal Resistance	Rotor Inertia	Weight	Shaft Loading*	
												Radial Force	Axial Force
		Parallel	Series	oz-in (Nm) +/-10%	Amps DC	Ohms +/-10%	mH Typical	oz-in (Nm)	Mounted °C/Watt	oz-in-s² (kg-m² x 10⁻³)	lb (kg)	lb (N)	lb (N)
Short Stack	T2HxxHK	•		74 (0.52)	5.3	0.19	0.63	2.0 (0.014)	6.14	0.00154 (0.0109)	1.1 (0.50)	15 (67)	25 (111)
	T2HxxHJ	•			4.0	0.28	1.0						
	T2HxxLH		•		2.7	0.64	2.5						
	T2HxxLD		•		1.1	3.6	16						
1 Stack	T21xxHK	•			5.4	0.23	1.1						
	T21xxHJ	•			4.1	0.33	1.8						
	T21xxLC		•	180 (1.27)	0.4	42.9	209	3.0 (0.021)	4.64	0.0034 (0.024)	1.5 (0.68)	15 (67)	25 (111)
	T21xxLH		•		2.7	0.85	4.6						
	T21xxLE		•		1.4	3.0	16						
	T21xxLD		•		1.1	4.9	30						

Me6: Kollmorgen Stepper Motor: T21xxLH Performance Curves

Assuming a power supply voltage of 24 VDC at 2.7A, the motor will draw 64.8 watts when operating.

Unlike most electric motors, stepper motors draw essentially the same power irregardless of the rotor motion (there is little back EMF generated).

The reduction in output torque with increased speed is the effect of stator inductance.



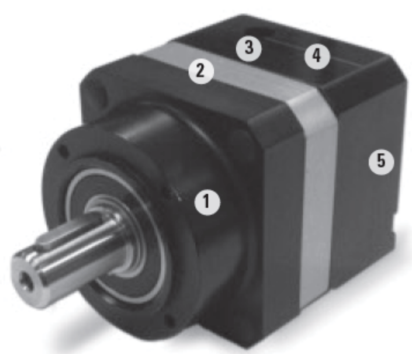
Me6: Kollmorgen Gearbox

XTRUE™

True Planetary™ Gearheads

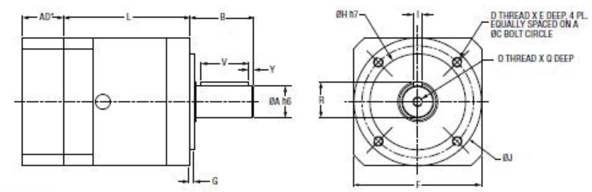
Ready for Immediate Delivery	
Precision	13 arc-minutes
Frame Sizes	40mm, 60mm, 80mm,120mm and 160mm
Torque Capacity	up to 876 Nm
Ratio Availability	3:1 thru 100:1
Radial load capacity	up to 3730 N
Mounting System	RediMount™

1. **Sealed deep groove ball bearings** provide high radial load carrying capability
2. **HRC 55-60 steel gears** provide superior wear resistance and increased backlash integrity
3. **Sealed deep groove ball bearing** provides precision alignment of sun gear
4. **RediMount™ system** provides error-free motor installation
5. **Anodized aluminum housing** reduces weight and prevents corrosion



XTRUE™

True Planetary™ Gearheads



*AD = Adapter Length
Adapter Length will vary depending on motor. Consult customer service for details.

Dimensions

Part Number	A Output Shaft Diameter mm [in]	B Output Shaft Length mm [in]	Y Shaft End Distance mm [in]	V Keyway Length mm [in]	R Keyway Height mm [in]	I Key Width mm [in]	H Pilot Diameter mm [in]	J Body Diameter mm [in]	G Pilot Length mm [in]
XT040	10 [0.39]	26 [1.02]	2.5 [0.10]	18 [0.71]	11.2 [0.44]	3 [0.12]	26 [1.02]	40 [1.57]	2 [0.08
XT060	14 [0.55]	35 [1.37]	2.5 [0.10]	25 [0.98]	16 [0.63]	5 [0.20]	40 [1.57]	60 [2.36]	3 [0.12
XT080	20 [0.79]	40 [1.57]	4.0 [0.16]	28 [1.10]	22.5 [0.89]	6 [0.24]	60 [2.36]	80 [3.15]	3 [0.12
XT120	25 [0.98]	55 [2.16]	5.0 [0.20]	40 [1.57]	28 [1.10]	8 [0.31]	80 [3.15]	115 [4.53]	4 [0.16
XT160	40 [1.57]	87 [3.42]	8.0 [0.32]	65 [2.55]	43 [1.69]	12 [0.47]	130 [5.12]	160 [6.30]	5 [0.20

Dimensions

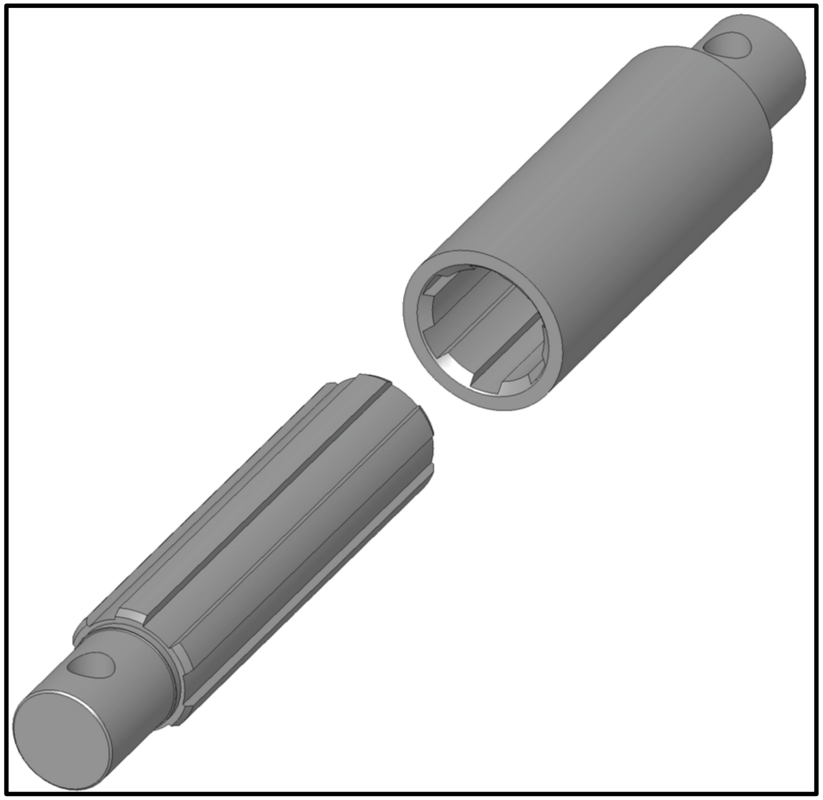
Part Number	D Thread	E Thread Depth mm [in]	O Output Shaft Thread	Q Thread Depth mm [in]	F Flange Square mm [in]	L Length mm [in]		C Bolt Circle mm [in]
						3:1 - 10:1	15:1 - 100:1	
XT040	M4	6 [0.24]	M3	9 [0.35]	42 [1.65]	36.5 [1.43]	49.5 [1.94]	34 [1.34]
XT060	M5	8 [0.31]	M5	12 [0.47]	61 [2.40]	51 [2.00]	68 [2.67]	52 [2.05]
XT080	M6	10 [0.39]	M6	16 [0.63]	90 [3.54]	67 [2.64]	90 [3.54]	70 [2.76]
XT120	M10	16 [0.63]	M10	22 [0.87]	119 [4.53]	87.3 [3.44]	179 [4.67]	100 [3.94]
XT160	M12	20 [0.79]	M16	36 [1.42]	142 [5.59]	119.6 [4.71]	168.9 [6.65]	145 [5.71]

Specifications

Part Number	Stages	Backlash (arc-min)	Efficiency	Weight kg	Weight [lbs]	Ratio Availablility
XT040	1 2	13 15	93% 88%	0.45 0.5	[1.0] [1.1]	3:1, 5:1, 10:1 15:1; 25:1, 30:1, 50:1, 100:1
XT060	1 2	13 15	93% 88%	1.0 1.2	[2.2] [2.6]	3:1, 4:1, 5:1, 7:1; 10:1 15:1, 20:1, 25:1, 30:1, 40:1,50:1; 70:1; 100:1
XT080	1 2	13 15	93% 88%	3.0 3.7	[6.6] [8.1]	3:1, 4:1, 5:1, 7:1; 8:1; 10:1 15:1, 20:1, 25:1, 30:1, 40:1, 50:1; 70:1; 80:1; 100
XT120	1 2	13 15	93% 88%	5.7 7.3	[12.5] [16.1]	3:1, 4:1, 5:1, 7:1; 10:1 15:1, 20:1, 25:1, 30:1, 40:1, 50:1; 70:1; 100:1
XT160	1 2	13 15	93% 88%	12.8 17.2	[28.2] [37.8]	3:1, 4:1, 5:1, 7:1; 10:1 15:1, 20:1, 25:1, 30:1, 40:1, 50:1; 70:1; 100:1

Me6: Mechanical Drive Spline

- From http://en.wikipedia.org/wiki/Spline_%28mechanical%29
- "Splines are ridges or teeth on a drive shaft that mesh with grooves in a mating piece and transfer torque to it, maintaining the angular correspondence between them.
- "For instance, a gear mounted on a shaft might use a male spline on the shaft that matches the female spline on the gear."



Me6: Transmissive Optical Switches

- **From http://sensing.honeywell.com/honeywell-sensing-optical-sensors-range-guide-006495-4-en.pdf**

- **Typical transmissive optical switches:**

Available in multiple package styles and mounting configurations, various slot widths, and aperture window sizes. Choice of phototransistor, photodarlington, or Optoschmitt output. Potential applications include printers/copiers, motion control, meters, data storage, scanning, automated transactions, and medical equipment.

Series	HOA1877	HOA825	HOA086X
Sensor aperture	1,52 mm [0.06 in] dia	1,52 mm [0.06 in] dia	1,52 mm x 1,27 mm [0.06 in x 0.05 in]
Slot width	9,53 mm [0.375 in]	4,19 mm [0.165 in]	3,18 mm [0.125 in]
Rise/fall time (typ.)	15 ns	15 ns	15 ns
Coupled current (Ic) min.	0.5 mA	0.5 mA	1 mA
Collector-emitter break-down voltage (min.)	30 V	30 V	30 V
Mounting configuration	mounting tabs	N, L, T, P mounting options	N, L, T, P mounting options
Termination style	0,46 mm [0.018 in] diameter leads	0,51 mm [0.020 in] sq leads	0,51 mm [0.020 in] sq leads
Measurements (H x W x L)	7,62 mm x 31,75 mm x 15,88 mm [0.3 in x 1.25 in x 0.625 in]	6,35 mm x 22,86 mm x 10,31 mm [0.25 in x 0.90 in x 0.41 in]	11,05 mm x 24,89 x 10,18 mm [0.44 in x 0.98 in x 0.40 in]
Features	phototransistor or photodar-lington output; wide operating temperature; high optical axis position	phototransistor output; four mounting configurations; plastic-molded components	phototransistor output; four mounting configurations; opaque or IR transmissive housings; plastic molded components

Me6: Optimizing filter change time by half-shifting

- The design described on slide 33 assumes the drive selector will engage one filter wheel at a time, rotating it from its open position, through successive filters, and back to its open position. Only then is the filter selector shifted to the next filter wheel to repeat the sequence.
- However, it would be possible to half-shift the filter selector axially while the last filter is staring. The half-shift engages the drive spline of two adjacent filter wheels. Now when the filter selector is rotated, it would simultaneously (a) rotate the previous wheel into its open position, and (b) rotate the next wheel into its first filter position.
- Then, during the stare time of that filter, the filter selector could complete its half-shift, completely disengaging from the previous wheel, and leave it ready to rotate only the current filter wheel.
- This technique would save some time in indexing through all 50 filters.
- If this technique is used, it would be advantageous to locate the filters that need a long stare time at the beginning and ending position of each filter wheel, so that the half-shift was completed before the stare was completed.

Me6: comments on design of filter wheel outer edge

- **The outer diameter of each filter wheel is used for several purposes:**
  - Provide a V surface for the guide bearing,
  - Have a notch for the spring detent, and
  - Have features at different radii to actuate the two photo-interruptors: six holes for the filters, and one hole for the open position.
- **The conflict is:**
  - The spring detent notch would interrupt the bearing surface; it could also inadvertently trigger the photo-interruptors.
- **Careful design will be needed to resolve these concerns.**
  - One approach would be to increase the thickness of the wheel to provide more space for these three functions. However, this would increase the overall length and mass of the mechanism.

GEO CAPE Filter Radiometer (FR)

~ Concept Presentations ~

Detectors

Carl Kotecki

Aug 12, 2014

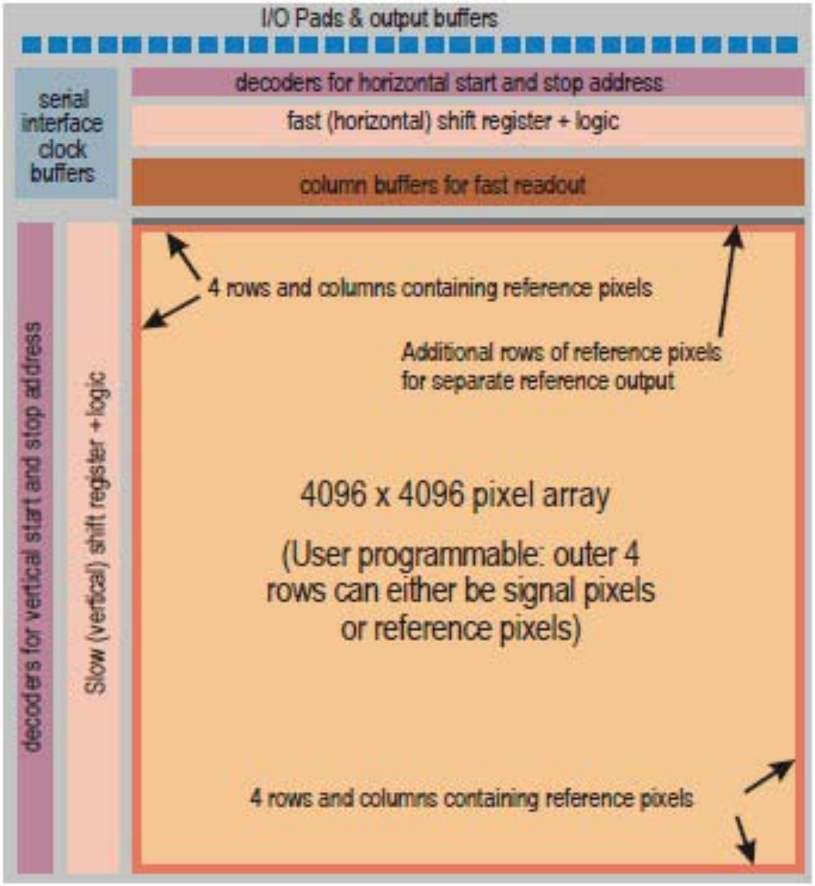
Detector Requirements

- **Filter Radiometer: UV-VIS-NIR-SWIR**
  - **UV-VIS-NIR:** 350nm thru 1020nm
    - Most filter bands are 5nm wide
    - Need a 2k x 2k array 250m GSD pixels
    - Standard large format 2-D arrays have 15 or 18um square pixels
      - The optical design could not get 80% encircled energy in a 15um square using a reasonably sized telescope. However, it was possible assuming a 2pixel x 2pixel "Superpixel". The detector array active area has to be a 4k X 4k array of 15um pixels.
    - Very large SNR requirements means the detector needs:
      - High QE
      - Low read noise
      - Low dark current/noise
      - Large well capacity
  - **SWIR 1245 and 1640nm**
    - 20 and 40nm bandwidths
    - Allowed to be achieved by binning up to a 4 x 4 array of 15 X 15um pixels (60um square superpixels of 500m GSD).
      - The atmospheric correction bands as well as diffraction limited optics allows for coarser spatial resolution at these wavelengths.
      - SNRs were achieved without performing this spatial binning

Detector Choices

- **UV-VIS-NIR Detector Choices**
  - Silicon is the best detector material choice
    - Hybrid PIN Photodiodes on ROICs such as the HAWAII-4RG
      - Low read noise, small well capacity, fixed square format
    - CCDs
      - Easily customized for array size and pixel size
      - Large well capacity
      - Low read noise
- **SWIR Detector Choices**
  - InGaAs
    - Readily available in 2-D formats with 1.7um cutoff material
    - Requires cooling to -20C or below to reduce dark current
    - Large well sizes with moderate read noise available
    - Material with cutoff wavelengths longer than 1.7um are more susceptible to radiation damage
      - Cutoff wavelength slightly longer than 1.7um is required because the knee in QE curve shifts to shorter wavelengths as the detector is cooled
  - Mercury Cadmium Telluride (MCT)
    - Requires lower temperature (185K) operation to minimize dark current
    - 2-D formats like the HAWAII-4RG readily available
      - Larger well capacity for MCT as opposed to silicon, still requires multiple reads to avoid saturation
- **UV-VIS-NIR and SWIR Detector Choices**
  - **Substrate removed MCT is the only choice**

Teledyne HAWAII-4RG



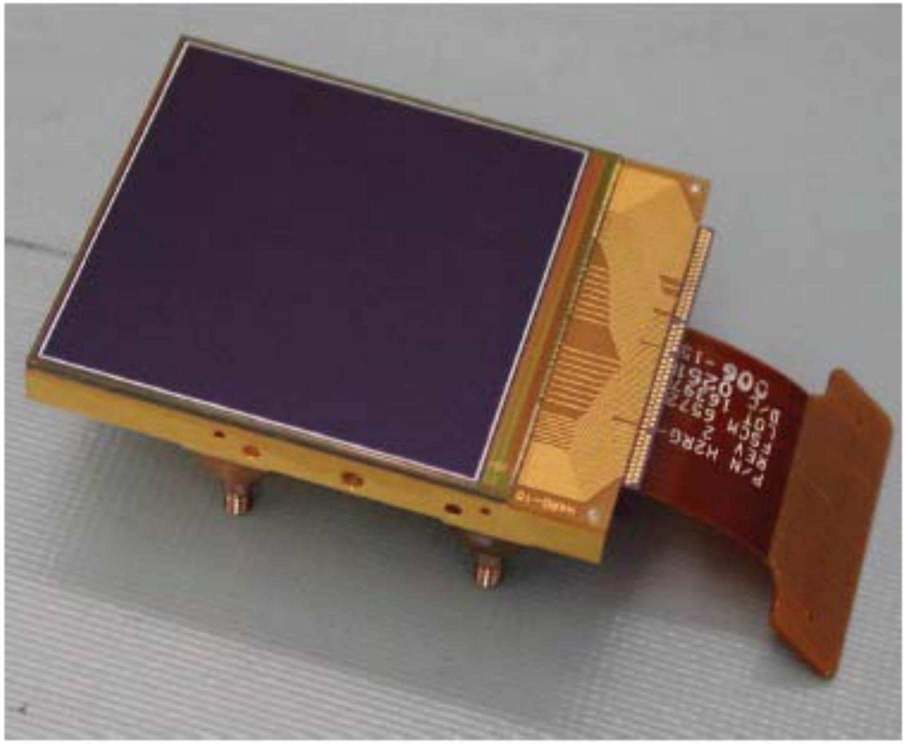
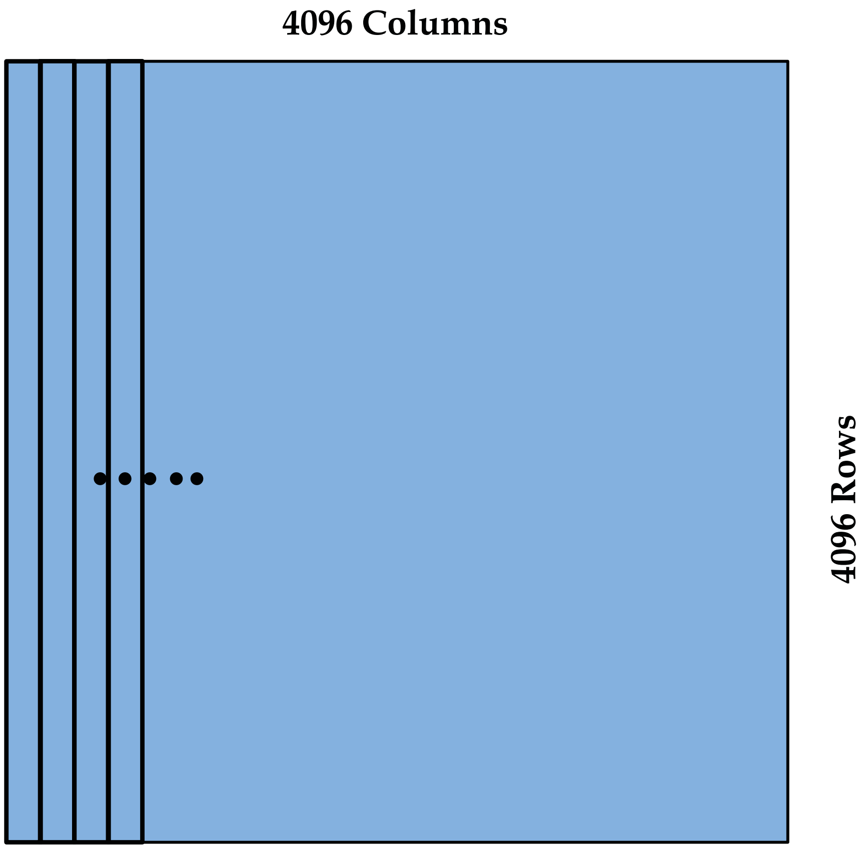


Figure 2: Block diagram (left) and photograph (right) of the HAWAII-4RG-10, hybridized to a HyViSI detector.

Note: Assembly comes complete from Teledyne with the MCT detector array chip, flip chip bump bonded to the Silicon ROIC, bonded to the ceramic (Al2O3) fanout board, bonded to the Molybdenum mount and micro-D connector. 1.7, 2.5 and 5um cutoff wavelength material are all standard products.

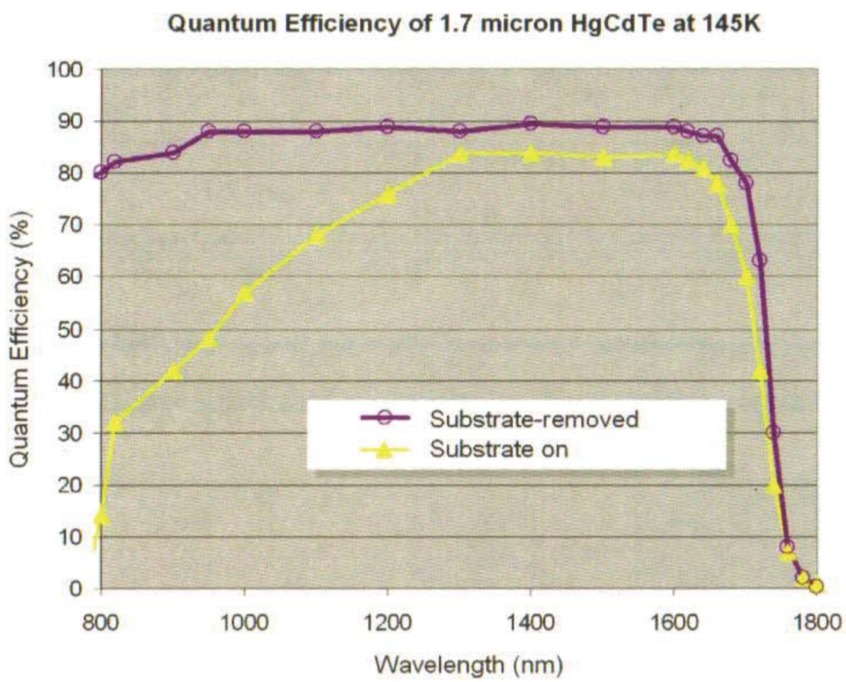
HAWAII-4RG Readout

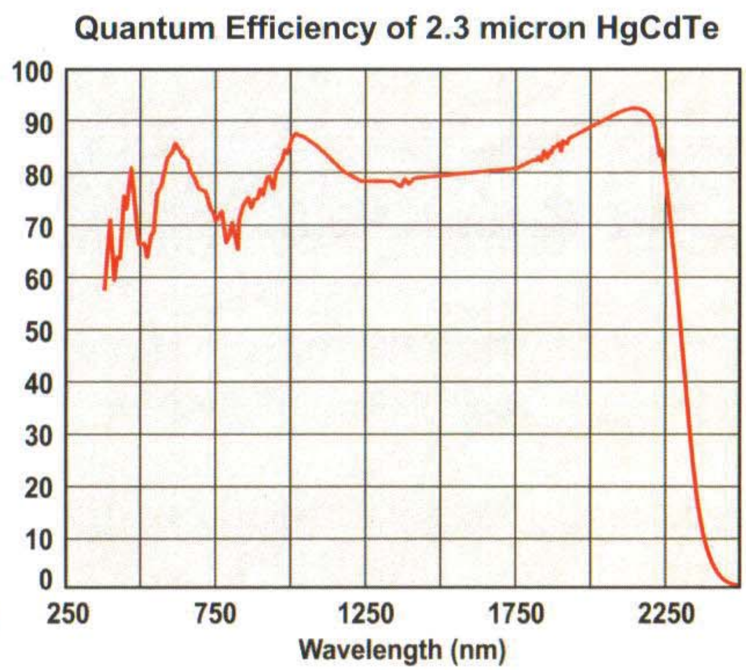
- **4k X 4k array of 15um pixels**
- **Bin multiple pixels in each band**
  - 2 x 2 pixels are summed in digital space to form the 30um x 30um super pixels
- **32 outputs from sections of 128 columns each**
- **128 X 4096 = 524,288 pixels per channel**
- **524,288 /0.24sec = ~2.185MHz**
  - But for CDS two reads per sample are required so actual read speed required is 2x or 4.369MHz
  - Output up to 10MHz is supported by both the ROIC and the SIDECAR 12 bit ADCs so plenty of margin



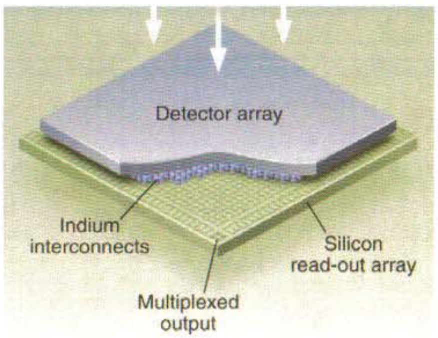
If the SWIR bands are dropped and the MCT is replaced with Si, the available well size is smaller and the number of reads would be greater to avoid saturation. The minimum integration time would require read speeds beyond the capability of the ROIC and SIDECAR.

Quantum Efficiency of Teledyne Substrate removed MCT





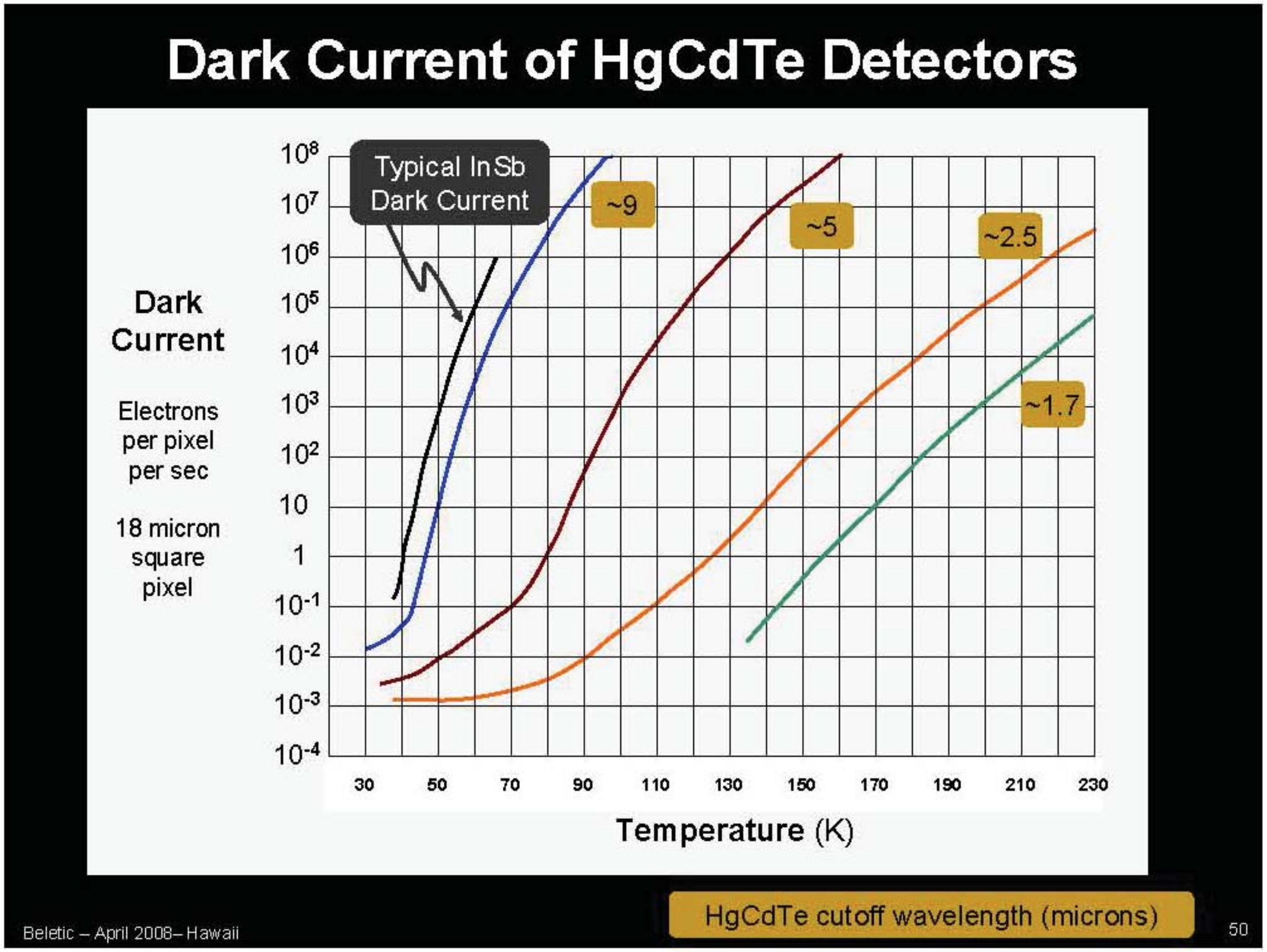
- Overall improved QE
  - Response to visible and UV
    - Less susceptible to cosmic rays



TELEDYNE IMAGING SENSORS

1

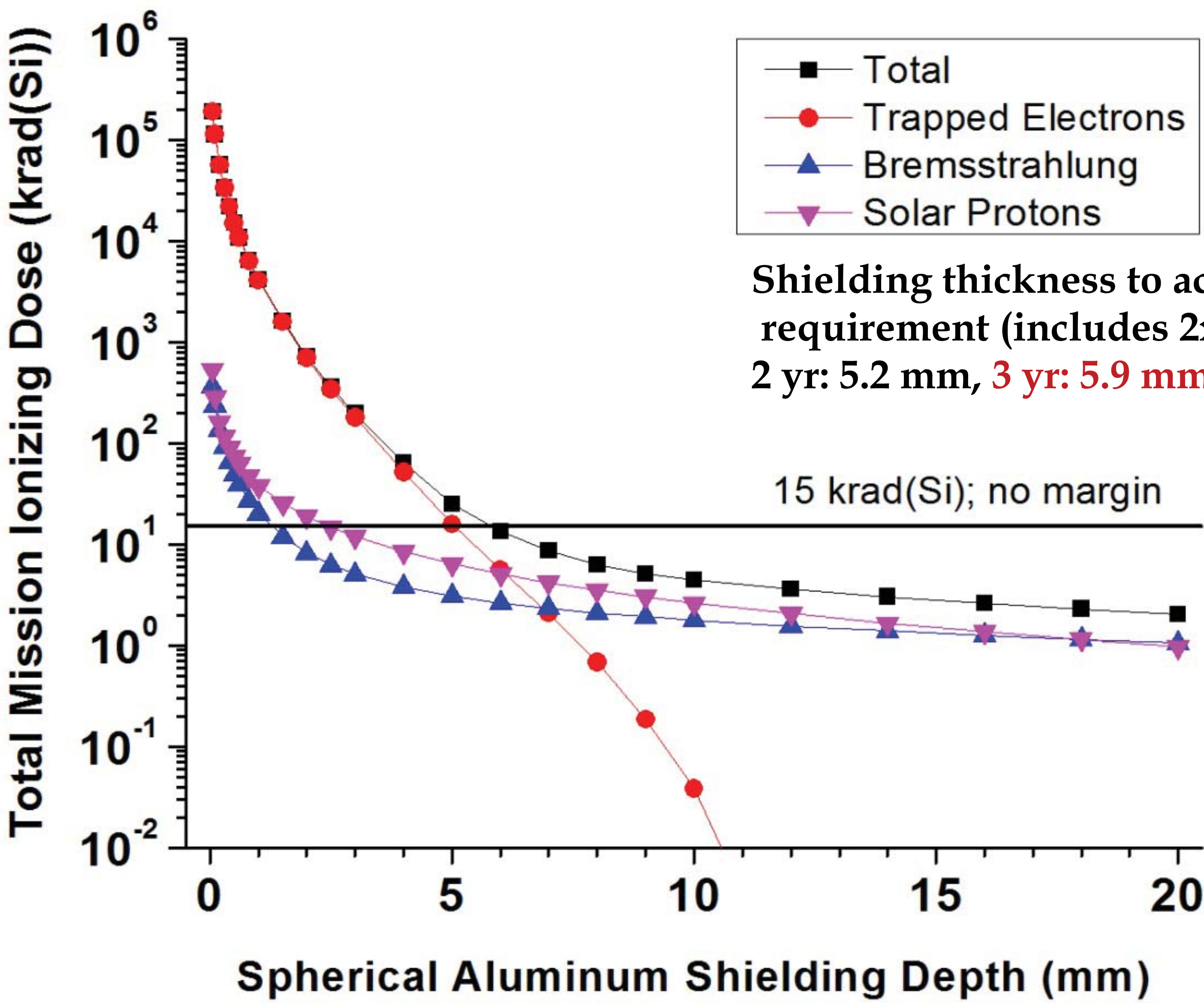
MCT Dark Current vs Temperature



- **Note: Data shown is for 18micron pixels. For 15microns pixels, values would be ~0.7X ($15^2/18^2$). 1.7um cutoff material at 185K would be ~150e-/pix/sec x 0.7 = ~100e-/pix/sec**

GEO Radiation Environment (for a 3 year mission)

Integrated Design Capability / Instrument Design Laboratory

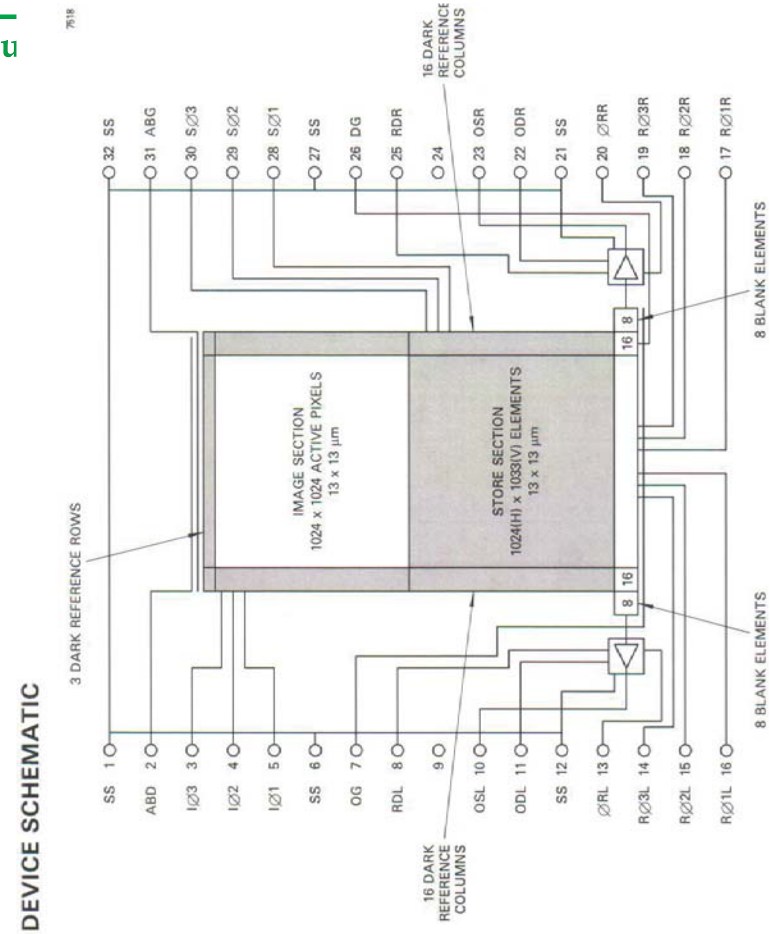


Shielding thickness to achieve 30 krad(Si) requirement (includes 2x margin, 2020 launch)
2 yr: 5.2 mm, 3 yr: 5.9 mm, 5 yr: 6.9 mm

{Courtesy Jonathan Pellish}

De-Scope UV-VIS-NIR Custom Frame Transfer CCD

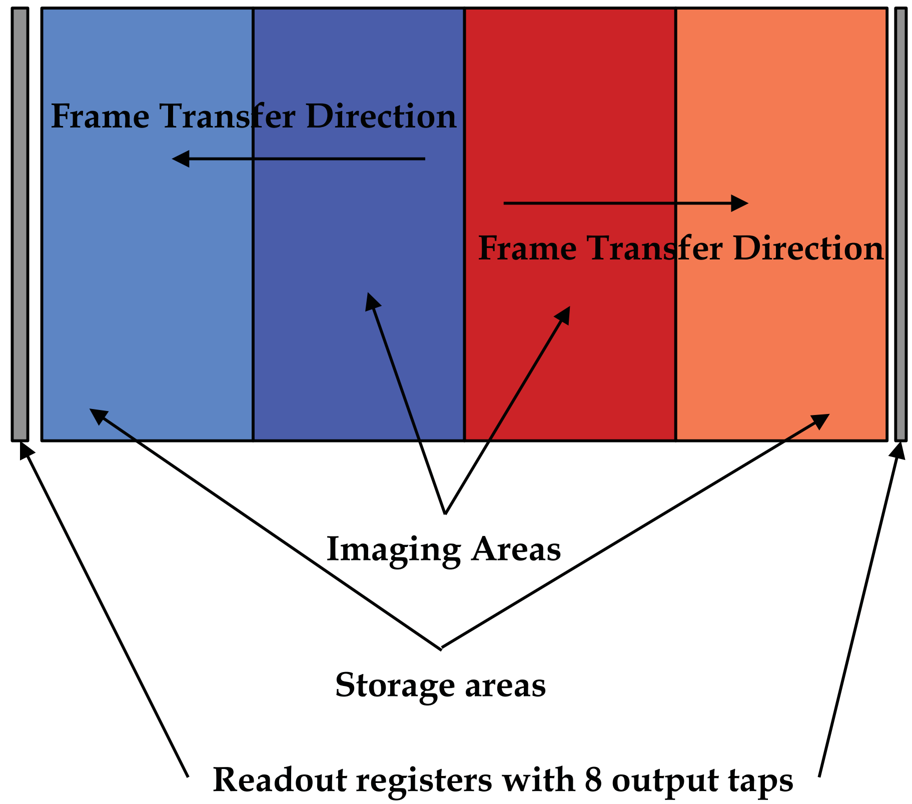
- **Use of a standard CCD is not an option:**
  - Cannot be read out fast enough to prevent incoming light during readout from corrupting the signal. So either a shutter or a frame transfer device is required.
    - Even so, 8 output taps are required to readout the array in 0.24sec
    - Vertical clock speed of ~200kHz shifts frame in ~0.01sec
  - No COTS frame transfer device with the right number of pixels, pixel size and number of outputs is available
    - Not an issue since CCDs are easily customized
    - At least two know possible vendors: STA, E2V
  - 4096 columns X 4096 rows, 15um X 15um pixels for the image area
  - (2) 2048 columns X 4096 rows, 15um X 15um pixels for the storage area
    - Additional rows and columns may be added for dark reference pixels



{For illustrative purposes: The actual CCD would have a 4k x 4k imaging area and (2) 4k x 2k storage areas}

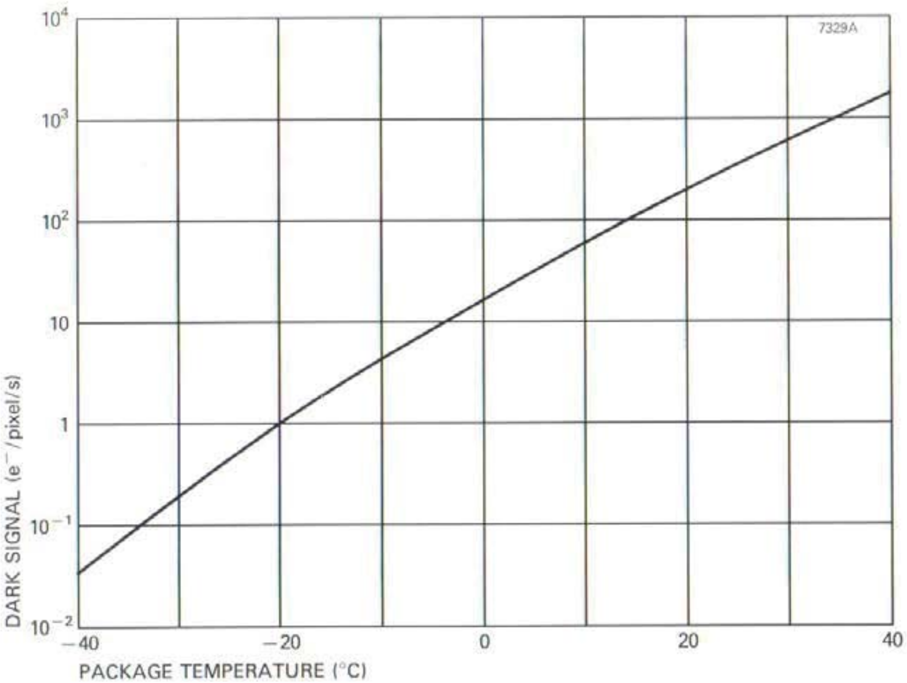
Split Frame, Frame Transfer CCD

- Single, split frame, frame transfer CCD
- 4k x 4k total Imaging area
- Two separate 4k x 2k storage areas
- Eight output taps on each side to enable high speed readout
- All pixels see the same wavelength light passed by the selected bandpass filter in the filter wheel



Typical CCD Characteristics

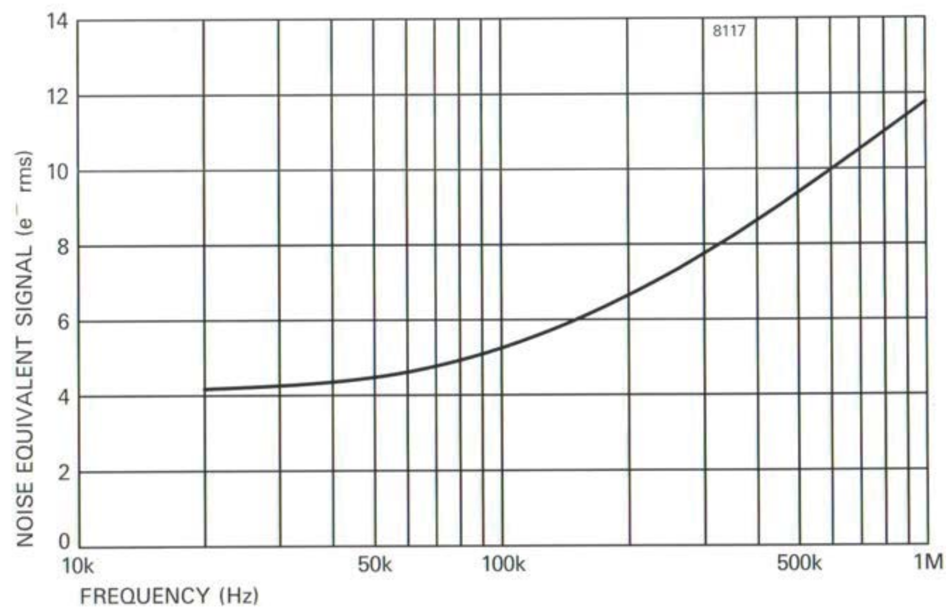
TYPICAL VARIATION OF DARK SIGNAL WITH TEMPERATURE (V_{SS} = +9.5 V)



Note: Plots for E2V devices with 26um square pixels. Dark current will be <70e-/pix/sec {~0.333 (225/676) times 200} at 20C.

Extrapolate read noise to ~14e- @ 2MHz

TYPICAL OUTPUT NOISE



CCD Camera Enclosure Notional Figure

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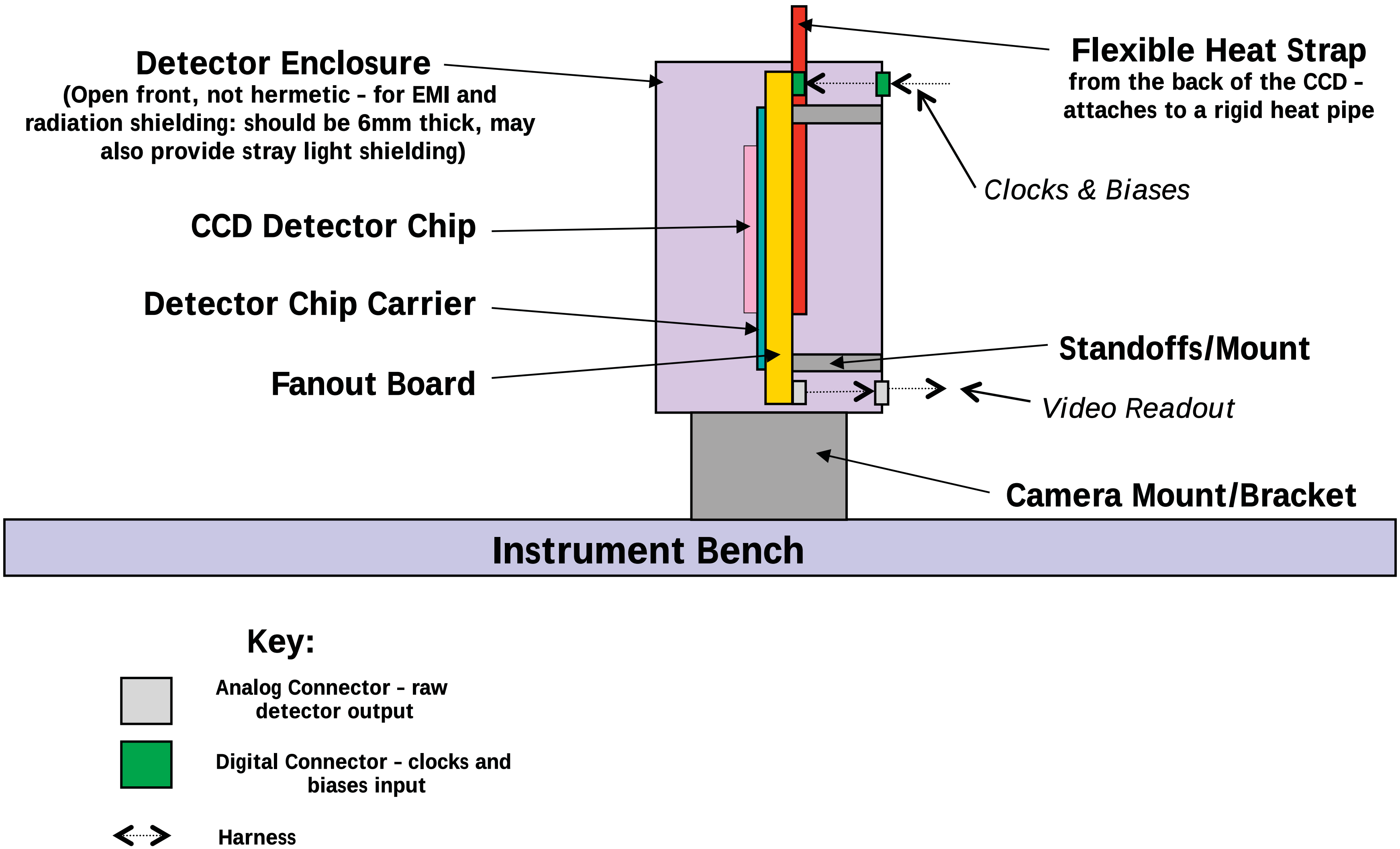


Note: The ceramic detector chip carrier comes with the silicon CCD chip permanently mounted.

Procurement Strategy

- **HAWAII-4RG 1.7um MCT**
  - One flight unit
  - One flight spare unit
  - At least three engineering units for radiation testing
    - Three for determining total dose effects since the major contributor is trapped electrons
      - Determine any increase in dark current and loss of QE in the MCT
      - Determine any total dose effect in the ROIC
        - The HAWAII-2RG was tested to 200krad without issue
    - Heavy ion testing is probably not necessary
      - HAWAII-2RG was tested without issue: The CMOS ROIC was not susceptible to SEUs, SEEs or latchup
        - H4RG uses the same CMOS 0.25um process and design rules as the H2RG
    - The engineering units can also be used for shake & bake qualification testing prior to radiation although no problems are anticipated (could even be waived)
- **Descope CCDs**
  - One flight CCD
  - One flight spare CCD
  - At least three engineering units for radiation testing for determining total dose effects since the major contributor are trapped electrons.
      - No SEUs (single event upsets) or SEEs (single event effects) possible from protons or heavy ions
    - The engineering units can also be used for shake & bake qualification testing prior to radiation although no problems are anticipated (could even be waived)

Conclusion/Concerns

- **No new technology development is required.**

- **1.7um cutoff MCT material is a standard product**
  - No expected issues with qualifying either the detector material or the ROIC
  - The quantum efficiency remains high at 1640nm despite cooling and being near the knee in the response curve.

- **Custom CCDs are readily available for the UV-VIS-NIR wavelengths.**
  - Radiation testing will be required. Typical commercial n-channel CCDs see significant degradation in performance between 5 and 35krad.
    - Increase in dark current, increased noise from traps, reduction in CTE and image smearing, hot pixels take out columns.

GEO CAPE Filter Radiometer (FR)

~ Concept Presentations ~

Radiometry

Jay Smith – SGT via Code 551
Mark Wilson, Carl Kotecki, Paul Earle
and Dick McBirney

Aug 14, 2014

Requirement Δ's from GEOCAPE Concept

- **Added 10% margin to the required SNR's to account for EOL degradations**
- **Added additional fixed 5nm Δλ bands (19 bands => 50 total channels)**
  - Channel band-center wavelengths, Δλ's , Ltyp's, and Lmax's provided by customer.
- **Fixed aperture diameter = 25 cm (effective clear aperture)**
- **Ground pixel resolution = 125 m**
  - Aggregate 2x2 pixels for 250m GSD resolution
- **Use [4096 x 4096] MCT and Si-CCD array with 15um pixel pitch**
  - Use SideCar ROIC for MCT ; FPGA control ROIC for Si-CCD array
  - 1000k pe well capacity for MCT ; 500K pe well capacity for Si CCD array
  - Dark current; 100 pe/pixel/sec at 185°K (Use same/equivalent spec for Si-CCD array)
  - 12 bit A/D Converter for MCT SIDECAR ; 14 bit A/D Converter for Si-CCD array
    - don't know the 'real' effective number of bits for either
  - 32 Readout Taps for MCT ; 16 Readout Taps for Si-CCD array
  - 10 MHz Tap readout for MCT SIDECAR ; Same spec for Si-CCD readout FPGA control ROIC
    - Need to limit Tap frequency to < 5MHz for CDS activity in order to maintain read noise spec
  - 100pe read noise for MCT ; 20pe read noise for Si-CCD array
- **Need to meet or exceed 50,000km²/min Scan Rate Coverage**

NOTE: the (QTY. 19) 5nm bands were analyzed with 10nm Ltyp & Lmax values

Fixed Engineering Parameters

$Orbit\_alt := 35786km$

Fixed Parameter's

$Aperture\_dia := 25cm$

$\tau\_filter\_step := 0.2sec$

$Scan\_rate := 50000 \frac{km^2}{min}$

$GSD := 125m$

$Filters := 50$

$Bin\_spatial := 4$

2x2 Bining to achieve 250m GSD

MCT - SideCar Data Spec's

$AD\_bits := 12$

$Taps := 32$

$Nr := 100$

$Well\_cap := 1000k$

Si-CCD - A/D & ROIC Data Spec's

$AD\_bits\_si := 14$

$Taps\_si := 16$

$Nr\_si := 20$

$Well\_cap\_si := 500k$

Detector Fixed Parameter's

$Array\_pixels := (4096)^2$

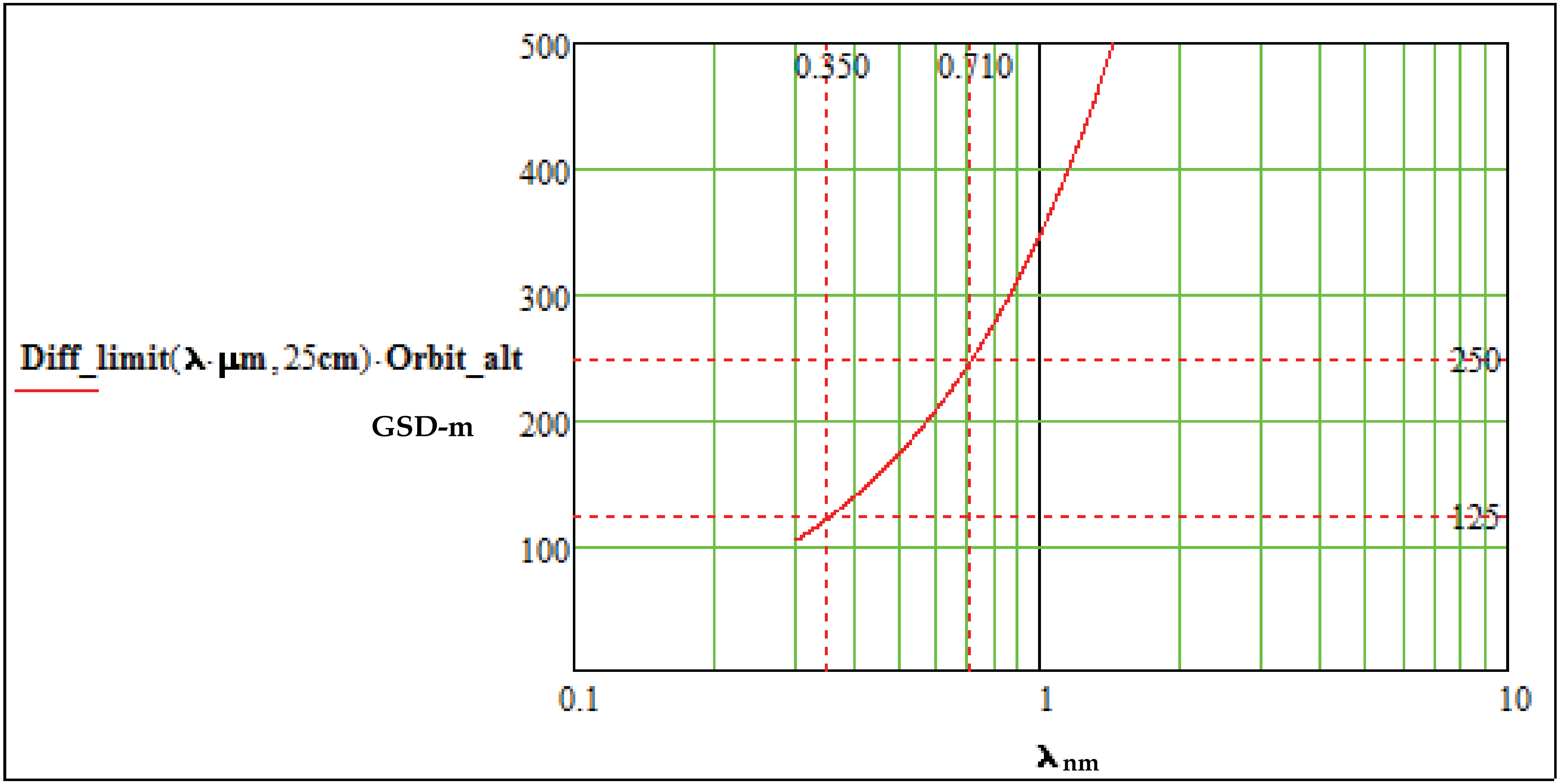
$I\_dk := 100Hz$

pe's / pixel / sec

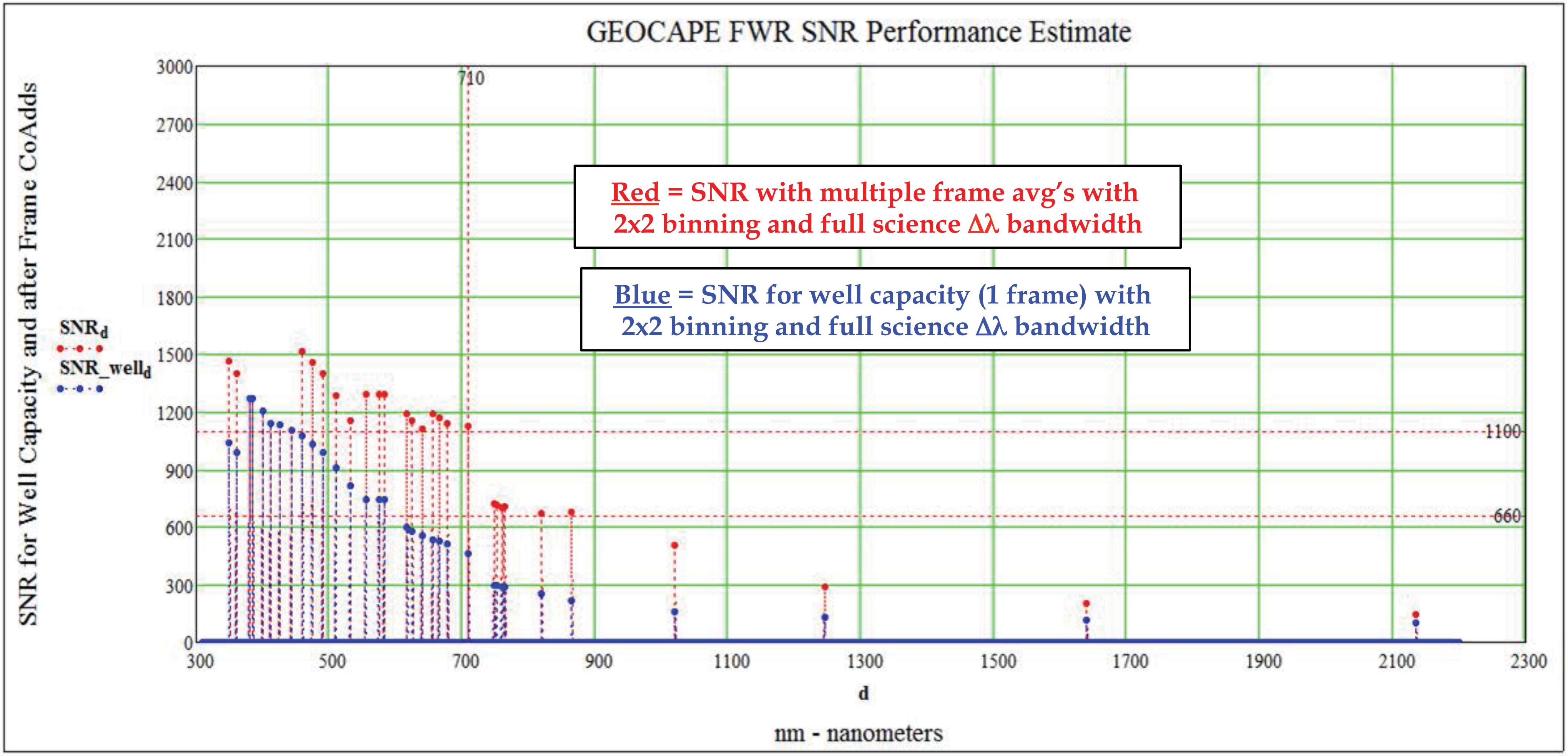
$Det\_sq := 15\mu m$

Diffraction Limit and Optical Crosstalk

$$\text{Diff\_limit}(\lambda, D) := 2.44 \cdot \frac{\lambda}{D}$$

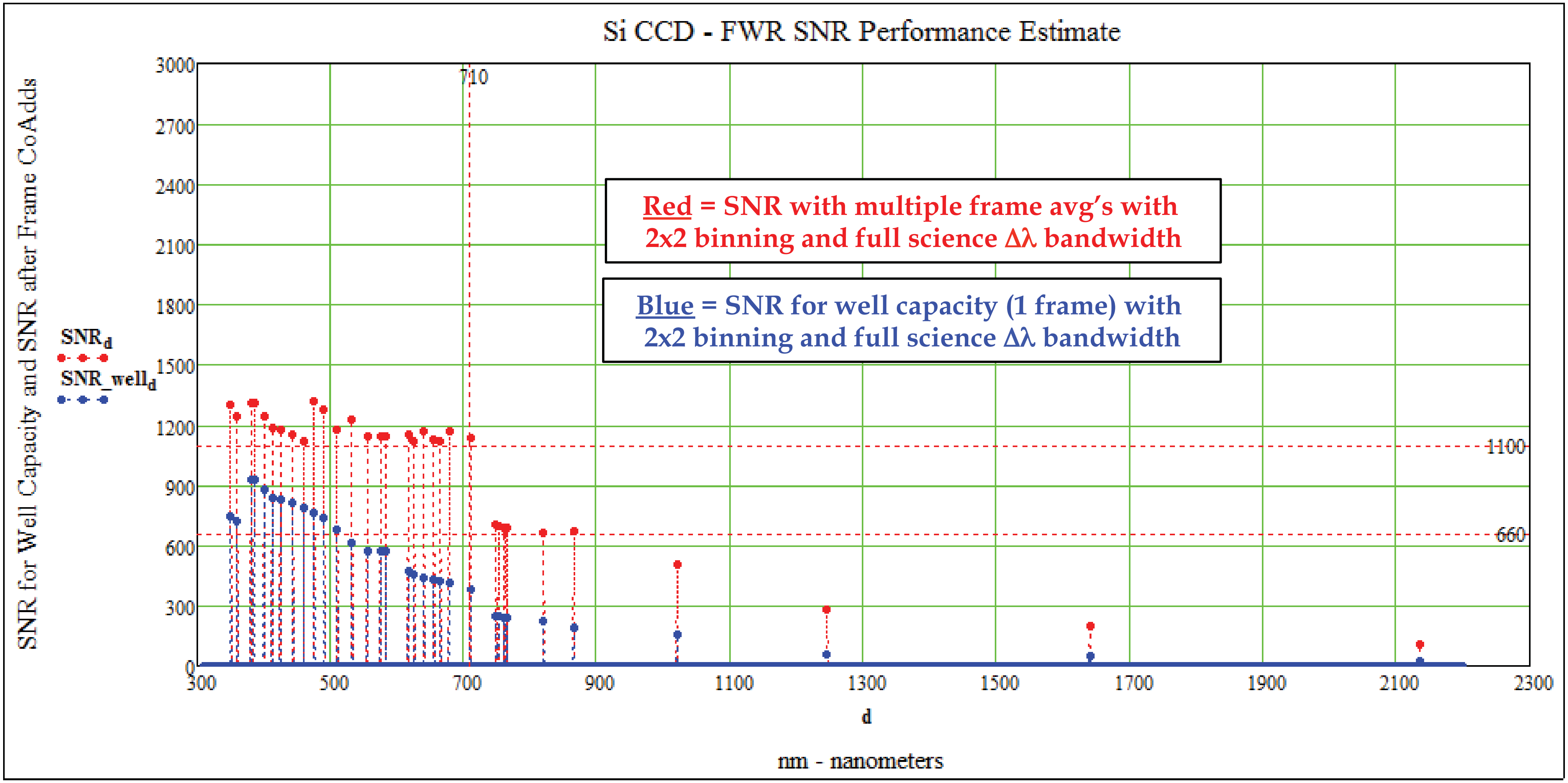


MCT - SNR Summary Graph



Si-CCD - SNR Summary Graph

Integrated Design Capability / Instrument Design Laboratory



Area Coverage Rate (MCT)

$CDS := 2$ Correlated Double Sampling

$$\mathrm{Readout}_d := \frac{\mathrm{Array\_pixels} \cdot \mathrm{CDS}}{\mathrm{Taps} \cdot \tau\_\mathrm{integ\_well}_d}$$

$$\max(\mathrm{Readout}) = 4.364 \cdot \mathrm{MHz}$$

$$\tau\_\mathrm{filter\_dwell}_d := \left(\tau\_\mathrm{integ\_well}_d \cdot \mathrm{Frames}_d\right)$$

$$\max(\tau\_\mathrm{filter\_dwell}) = 7.931\,\mathrm{s}$$

$$\tau\_\mathrm{filter\_wheel\_cycle} := \left[\sum_d \left(\tau\_\mathrm{filter\_dwell}_d \cdot b_d\right)\right] + [(\mathrm{Filters} - 1) \cdot (\tau\_\mathrm{filter\_step})] = 157.122\,\mathrm{s}$$

$$\mathrm{Scan\_rate\_Coverage} := \frac{\mathrm{Array\_pixels} \cdot \mathrm{GSD}^2}{\tau\_\mathrm{filter\_wheel\_cycle}} = 100105 \cdot \frac{\mathrm{km}^2}{\mathrm{min}}$$

Area Coverage Rate (Si-CCD)

CDS = Correlated Double Sampling

$$\text{Readout}_d := \frac{\text{Array\_pixels} \cdot \text{CDS}}{\text{Taps} \cdot \tau\text{\_integ\_well}_d}$$

$$\max(\text{Readout}) = 4.274 \cdot \text{MHz}$$

$$\tau\text{\_filter\_dwell}_{ee} := \left(\tau\text{\_integ\_well}_{ee} \cdot \text{Frames}_{ee}\right)$$

$$\max(\tau\text{\_filter\_dwell}) = 8\,\text{s}$$

$$\tau\text{\_filter\_wheel\_cycle\_si} := \left[\sum_{ee} \left(\tau\text{\_filter\_dwell}_{ee} \cdot b_{ee}\right)\right] + \left[(\text{Filters} - 3) \cdot (\tau\text{\_filter\_step})\right] = 172.078\,\text{s}$$

$$\text{Scan\_rate\_Coverage\_si} := \frac{\text{Array\_pixels} \cdot \text{GSD}^2}{\tau\text{\_filter\_wheel\_cycle\_si}} = 91404 \cdot \frac{\text{km}^2}{\text{min}}$$

SNR Sensitivity Comparison

Integrated Design Capability / Instrument Design Laboratory

MCT		Si-CCD
$\frac{Well\_cap}{\sqrt{Well\_cap}} = 1000$	Ideal - SN Limited	$\frac{Well\_cap\_si}{\sqrt{Well\_cap\_si}} = 707$
$\frac{Well\_cap}{\sqrt{Well\_cap + Nr^2 + Nq^2}} = 993$	Modeled	$\frac{Well\_cap\_si}{\sqrt{Well\_cap\_si + Nr\_si^2 + Nq\_si^2}} = 707$
$\frac{Well\_cap}{\sqrt{Well\_cap + Nq^2}} = 998$		$\frac{Well\_cap\_si}{\sqrt{Well\_cap\_si + Nq\_si^2}} = 707$
$\frac{Well\_cap}{\sqrt{Well\_cap + Nr^2}} = 995$	Nr - Largest effect on MCT	$\frac{Well\_cap\_si}{\sqrt{Well\_cap\_si + Nr\_si^2}} = 707$

Slight Edge goes to Read Noise impact on MCT
Little effect on the Si-CCD performance

Summary

- **GOOD**
  - MCT and Si-CCD detector options - meet all Science Requirements
  - Both Detector options allow for > 50,000km^2/min scan rate
    - MCT has a slight edge due to the larger well capacity
- **BAD**
  - It's still not a spectrometer
  - Will require multiple 'hand picked' filter attenuators to limit Si-CCD ROIC readout tap frequency
- **UGLY**
  - Lots of filters to characterize for spatial uniformity (< 1000:1 ?)
    - Transmission, wavelength, wedge, … etc.

Backup Charts

MCT - FW Radiometer Summary_1

Integrated Design Capability / Instrument Design Laboratory

$\Delta\lambda_{350}$ = 15·nm	Atten$_{350}$ = 1	τ_integ_well$_{350}$ = 1.321 s	Readout$_{350}$ = 0.794·MHz	CoAdds$_{350}$ = 4	SNR_well$_{350}$ = 1035	Frames$_{350}$ = 2	SNR$_{350}$ = 1464	SNR_req$_{350}$ = 1100
$\Delta\lambda_{360}$ = 10·nm	Atten$_{360}$ = 1	τ_integ_well$_{360}$ = 1.485 s	Readout$_{360}$ = 0.706·MHz	CoAdds$_{360}$ = 4	SNR_well$_{360}$ = 988	Frames$_{360}$ = 2	SNR$_{360}$ = 1398	SNR_req$_{360}$ = 1100
$\Delta\lambda_{380}$ = 5·nm	Atten$_{380}$ = 1	τ_integ_well$_{380}$ = 2.51 s	Readout$_{380}$ = 0.418·MHz	CoAdds$_{380}$ = 8	SNR_well$_{380}$ = 1270	Frames$_{380}$ = 1	SNR$_{380}$ = 1270	SNR_req$_{380}$ = 1100
$\Delta\lambda_{400}$ = 5·nm	Atten$_{400}$ = 1	τ_integ_well$_{400}$ = 1.541 s	Readout$_{400}$ = 0.68·MHz	CoAdds$_{400}$ = 8	SNR_well$_{400}$ = 1204	Frames$_{400}$ = 1	SNR$_{400}$ = 1204	SNR_req$_{400}$ = 1100
$\Delta\lambda_{412}$ = 5·nm	Atten$_{412}$ = 1	τ_integ_well$_{412}$ = 1.11 s	Readout$_{412}$ = 0.945·MHz	CoAdds$_{412}$ = 8	SNR_well$_{412}$ = 1139	Frames$_{412}$ = 1	SNR$_{412}$ = 1139	SNR_req$_{412}$ = 1100
$\Delta\lambda_{425}$ = 5·nm	Atten$_{425}$ = 1	τ_integ_well$_{425}$ = 1.063 s	Readout$_{425}$ = 0.986·MHz	CoAdds$_{425}$ = 8	SNR_well$_{425}$ = 1132	Frames$_{425}$ = 1	SNR$_{425}$ = 1132	SNR_req$_{425}$ = 1100
$\Delta\lambda_{443}$ = 5·nm	Atten$_{443}$ = 1	τ_integ_well$_{443}$ = 1.037 s	Readout$_{443}$ = 1.011·MHz	CoAdds$_{443}$ = 8	SNR_well$_{443}$ = 1103	Frames$_{443}$ = 1	SNR$_{443}$ = 1103	SNR_req$_{443}$ = 1100
$\Delta\lambda_{460}$ = 5·nm	Atten$_{460}$ = 1	τ_integ_well$_{460}$ = 1.062 s	Readout$_{460}$ = 0.987·MHz	CoAdds$_{460}$ = 8	SNR_well$_{460}$ = 1072	Frames$_{460}$ = 2	SNR$_{460}$ = 1517	SNR_req$_{460}$ = 1100
$\Delta\lambda_{475}$ = 5·nm	Atten$_{475}$ = 1	τ_integ_well$_{475}$ = 1.024 s	Readout$_{475}$ = 1.024·MHz	CoAdds$_{475}$ = 8	SNR_well$_{475}$ = 1030	Frames$_{475}$ = 2	SNR$_{475}$ = 1456	SNR_req$_{475}$ = 1100
$\Delta\lambda_{490}$ = 5·nm	Atten$_{490}$ = 1	τ_integ_well$_{490}$ = 0.982 s	Readout$_{490}$ = 1.068·MHz	CoAdds$_{490}$ = 8	SNR_well$_{490}$ = 990	Frames$_{490}$ = 2	SNR$_{490}$ = 1400	SNR_req$_{490}$ = 1100
$\Delta\lambda_{510}$ = 5·nm	Atten$_{510}$ = 1	τ_integ_well$_{510}$ = 0.909 s	Readout$_{510}$ = 1.153·MHz	CoAdds$_{510}$ = 8	SNR_well$_{510}$ = 906	Frames$_{510}$ = 2	SNR$_{510}$ = 1281	SNR_req$_{510}$ = 1100
$\Delta\lambda_{532}$ = 5·nm	Atten$_{532}$ = 1	τ_integ_well$_{532}$ = 0.853 s	Readout$_{532}$ = 1.23·MHz	CoAdds$_{532}$ = 8	SNR_well$_{532}$ = 813	Frames$_{532}$ = 2	SNR$_{532}$ = 1150	SNR_req$_{532}$ = 1100
$\Delta\lambda_{555}$ = 5·nm	Atten$_{555}$ = 1	τ_integ_well$_{555}$ = 0.857 s	Readout$_{555}$ = 1.224·MHz	CoAdds$_{555}$ = 8	SNR_well$_{555}$ = 746	Frames$_{555}$ = 3	SNR$_{555}$ = 1292	SNR_req$_{555}$ = 1100
$\Delta\lambda_{583}$ = 5·nm	Atten$_{583}$ = 1	τ_integ_well$_{583}$ = 0.824 s	Readout$_{583}$ = 1.273·MHz	CoAdds$_{583}$ = 8	SNR_well$_{583}$ = 746	Frames$_{583}$ = 3	SNR$_{583}$ = 1292	SNR_req$_{583}$ = 1100
$\Delta\lambda_{617}$ = 5·nm	Atten$_{617}$ = 1	τ_integ_well$_{617}$ = 0.795 s	Readout$_{617}$ = 1.319·MHz	CoAdds$_{617}$ = 8	SNR_well$_{617}$ = 596	Frames$_{617}$ = 4	SNR$_{617}$ = 1192	SNR_req$_{617}$ = 1100
$\Delta\lambda_{625}$ = 5·nm	Atten$_{625}$ = 1	τ_integ_well$_{625}$ = 0.802 s	Readout$_{625}$ = 1.307·MHz	CoAdds$_{625}$ = 8	SNR_well$_{625}$ = 576	Frames$_{625}$ = 4	SNR$_{625}$ = 1153	SNR_req$_{625}$ = 1100

MCT - FW Radiometer Summary_2

$\Delta\lambda_{640} = 5\cdot nm$	$Atten_{640} = 1$	$\tau\_integ\_well_{640} = 0.789\, s$	$Readout_{640} = 1.329\cdot MHz$	$CoAdds_{640} = 8$	$SNR\_well_{640} = 555$	$Frames_{640} = 4$	$SNR_{640} = 1111$	$SNR\_req_{640} = 1100$
$\Delta\lambda_{655} = 5\cdot nm$	$Atten_{655} = 1$	$\tau\_integ\_well_{655} = 0.793\, s$	$Readout_{655} = 1.322\cdot MHz$	$CoAdds_{655} = 8$	$SNR\_well_{655} = 532$	$Frames_{655} = 5$	$SNR_{655} = 1189$	$SNR\_req_{655} = 1100$
$\Delta\lambda_{665} = 5\cdot nm$	$Atten_{665} = 1$	$\tau\_integ\_well_{665} = 0.796\, s$	$Readout_{665} = 1.317\cdot MHz$	$CoAdds_{665} = 8$	$SNR\_well_{665} = 523$	$Frames_{665} = 5$	$SNR_{665} = 1169$	$SNR\_req_{665} = 1100$
$\Delta\lambda_{678} = 5\cdot nm$	$Atten_{678} = 1$	$\tau\_integ\_well_{678} = 0.799\, s$	$Readout_{678} = 1.313\cdot MHz$	$CoAdds_{678} = 8$	$SNR\_well_{678} = 511$	$Frames_{678} = 5$	$SNR_{678} = 1143$	$SNR\_req_{678} = 1100$
$\Delta\lambda_{710} = 5\cdot nm$	$Atten_{710} = 1$	$\tau\_integ\_well_{710} = 0.802\, s$	$Readout_{710} = 1.308\cdot MHz$	$CoAdds_{710} = 8$	$SNR\_well_{710} = 459$	$Frames_{710} = 6$	$SNR_{710} = 1125$	$SNR\_req_{710} = 1100$
$\Delta\lambda_{748} = 10\cdot nm$	$Atten_{748} = 1$	$\tau\_integ\_well_{748} = 0.4\, s$	$Readout_{748} = 2.621\cdot MHz$	$CoAdds_{748} = 4$	$SNR\_well_{748} = 295$	$Frames_{748} = 6$	$SNR_{748} = 722$	$SNR\_req_{748} = 660$
$\Delta\lambda_{752} = 5\cdot nm$	$Atten_{752} = 1$	$\tau\_integ\_well_{752} = 0.804\, s$	$Readout_{752} = 1.304\cdot MHz$	$CoAdds_{752} = 4$	$SNR\_well_{752} = 292$	$Frames_{752} = 6$	$SNR_{752} = 716$	$SNR\_req_{752} = 660$
$\Delta\lambda_{760} = 3\cdot nm$	$Atten_{760} = 1$	$\tau\_integ\_well_{760} = 1.322\, s$	$Readout_{760} = 0.793\cdot MHz$	$CoAdds_{760} = 4$	$SNR\_well_{760} = 287$	$Frames_{760} = 6$	$SNR_{760} = 703$	$SNR\_req_{760} = 660$
$\Delta\lambda_{763} = 3\cdot nm$	$Atten_{763} = 1$	$\tau\_integ\_well_{763} = 1.313\, s$	$Readout_{763} = 0.799\cdot MHz$	$CoAdds_{763} = 4$	$SNR\_well_{763} = 285$	$Frames_{763} = 6$	$SNR_{763} = 697$	$SNR\_req_{763} = 660$
$\Delta\lambda_{765} = 40\cdot nm$	$Atten_{765} = 0.4$	$\tau\_integ\_well_{765} = 0.24\, s$	$Readout_{765} = 4.364\cdot MHz$	$CoAdds_{765} = 4$	$SNR\_well_{765} = 288$	$Frames_{765} = 6$	$SNR_{765} = 706$	$SNR\_req_{765} = 660$
$\Delta\lambda_{820} = 15\cdot nm$	$Atten_{820} = 1$	$\tau\_integ\_well_{820} = 0.264\, s$	$Readout_{820} = 3.974\cdot MHz$	$CoAdds_{820} = 4$	$SNR\_well_{820} = 255$	$Frames_{820} = 7$	$SNR_{820} = 674$	$SNR\_req_{820} = 660$
$\Delta\lambda_{865} = 40\cdot nm$	$Atten_{865} = 0.4$	$\tau\_integ\_well_{865} = 0.256\, s$	$Readout_{865} = 4.092\cdot MHz$	$CoAdds_{865} = 4$	$SNR\_well_{865} = 213$	$Frames_{865} = 10$	$SNR_{865} = 675$	$SNR\_req_{865} = 660$
$\Delta\lambda_{1020} = 40\cdot nm$	$Atten_{1020} = 0.4$	$\tau\_integ\_well_{1020} = 0.251\, s$	$Readout_{1020} = 4.172\cdot MHz$	$CoAdds_{1020} = 4$	$SNR\_well_{1020} = 161$	$Frames_{1020} = 10$	$SNR_{1020} = 508$	$SNR\_req_{1020} = 495$
$\Delta\lambda_{1245} = 20\cdot nm$	$Atten_{1245} = 1$	$\tau\_integ\_well_{1245} = 0.316\, s$	$Readout_{1245} = 3.323\cdot MHz$	$CoAdds_{1245} = 4$	$SNR\_well_{1245} = 130$	$Frames_{1245} = 5$	$SNR_{1245} = 291$	$SNR\_req_{1245} = 275$
$\Delta\lambda_{1640} = 40\cdot nm$	$Atten_{1640} = 1$	$\tau\_integ\_well_{1640} = 0.349\, s$	$Readout_{1640} = 3.007\cdot MHz$	$CoAdds_{1640} = 4$	$SNR\_well_{1640} = 117$	$Frames_{1640} = 3$	$SNR_{1640} = 202$	$SNR\_req_{1640} = 198$
$\Delta\lambda_{2135} = 50\cdot nm$	$Atten_{2135} = 1$	$\tau\_integ\_well_{2135} = 0.777\, s$	$Readout_{2135} = 1.35\cdot MHz$	$CoAdds_{2135} = 4$	$SNR\_well_{2135} = 100$	$Frames_{2135} = 2$	$SNR_{2135} = 141$	$SNR\_req_{2135} = 110$

Si-CCD - FW Radiometer Summary_1

Integrated Design Capability / Instrument Design Laboratory

$\Delta\lambda_{350} = 15 \cdot nm$	$Atten_{350} = 1$	$\tau\_integ\_well_{350} = 0.599\ s$	$Readout_{350} = 3.503 \cdot MHz$	$CoAdds_{350} = 4$	$SNR\_well_{350} = 750$	$Frames_{350} = 3$	$SNR_{350} = 1299$	$SNR\_req_{350} = 1100$
$\Delta\lambda_{360} = 10 \cdot nm$	$Atten_{360} = 1$	$\tau\_integ\_well_{360} = 0.73\ s$	$Readout_{360} = 2.873 \cdot MHz$	$CoAdds_{360} = 4$	$SNR\_well_{360} = 718$	$Frames_{360} = 3$	$SNR_{360} = 1243$	$SNR\_req_{360} = 1100$
$\Delta\lambda_{380} = 5 \cdot nm$	$Atten_{380} = 1$	$\tau\_integ\_well_{380} = 1.178\ s$	$Readout_{380} = 1.781 \cdot MHz$	$CoAdds_{380} = 8$	$SNR\_well_{380} = 927$	$Frames_{380} = 2$	$SNR_{380} = 1310$	$SNR\_req_{380} = 1100$
$\Delta\lambda_{400} = 5 \cdot nm$	$Atten_{400} = 1$	$\tau\_integ\_well_{400} = 0.699\ s$	$Readout_{400} = 3.001 \cdot MHz$	$CoAdds_{400} = 8$	$SNR\_well_{400} = 881$	$Frames_{400} = 2$	$SNR_{400} = 1247$	$SNR\_req_{400} = 1100$
$\Delta\lambda_{412} = 5 \cdot nm$	$Atten_{412} = 1$	$\tau\_integ\_well_{412} = 0.508\ s$	$Readout_{412} = 4.128 \cdot MHz$	$CoAdds_{412} = 8$	$SNR\_well_{412} = 837$	$Frames_{412} = 2$	$SNR_{412} = 1183$	$SNR\_req_{412} = 1100$
$\Delta\lambda_{425} = 5 \cdot nm$	$Atten_{425} = 1$	$\tau\_integ\_well_{425} = 0.492\ s$	$Readout_{425} = 4.266 \cdot MHz$	$CoAdds_{425} = 8$	$SNR\_well_{425} = 832$	$Frames_{425} = 2$	$SNR_{425} = 1176$	$SNR\_req_{425} = 1100$
$\Delta\lambda_{443} = 5 \cdot nm$	$Atten_{443} = 1$	$\tau\_integ\_well_{443} = 0.491\ s$	$Readout_{443} = 4.274 \cdot MHz$	$CoAdds_{443} = 8$	$SNR\_well_{443} = 812$	$Frames_{443} = 2$	$SNR_{443} = 1148$	$SNR\_req_{443} = 1100$
$\Delta\lambda_{460} = 5 \cdot nm$	$Atten_{460} = 1$	$\tau\_integ\_well_{460} = 0.502\ s$	$Readout_{460} = 4.174 \cdot MHz$	$CoAdds_{460} = 8$	$SNR\_well_{460} = 791$	$Frames_{460} = 2$	$SNR_{460} = 1119$	$SNR\_req_{460} = 1100$
$\Delta\lambda_{475} = 5 \cdot nm$	$Atten_{475} = 1$	$\tau\_integ\_well_{475} = 0.491\ s$	$Readout_{475} = 4.267 \cdot MHz$	$CoAdds_{475} = 8$	$SNR\_well_{475} = 762$	$Frames_{475} = 3$	$SNR_{475} = 1320$	$SNR\_req_{475} = 1100$
$\Delta\lambda_{490} = 5 \cdot nm$	$Atten_{490} = 0.55$	$\tau\_integ\_well_{490} = 0.835\ s$	$Readout_{490} = 2.512 \cdot MHz$	$CoAdds_{490} = 8$	$SNR\_well_{490} = 735$	$Frames_{490} = 3$	$SNR_{490} = 1272$	$SNR\_req_{490} = 1100$
$\Delta\lambda_{510} = 5 \cdot nm$	$Atten_{510} = 0.55$	$\tau\_integ\_well_{510} = 0.774\ s$	$Readout_{510} = 2.711 \cdot MHz$	$CoAdds_{510} = 8$	$SNR\_well_{510} = 678$	$Frames_{510} = 3$	$SNR_{510} = 1174$	$SNR\_req_{510} = 1100$
$\Delta\lambda_{532} = 5 \cdot nm$	$Atten_{532} = 0.55$	$\tau\_integ\_well_{532} = 0.717\ s$	$Readout_{532} = 2.925 \cdot MHz$	$CoAdds_{532} = 8$	$SNR\_well_{532} = 615$	$Frames_{532} = 4$	$SNR_{532} = 1231$	$SNR\_req_{532} = 1100$
$\Delta\lambda_{555} = 5 \cdot nm$	$Atten_{555} = 0.55$	$\tau\_integ\_well_{555} = 0.712\ s$	$Readout_{555} = 2.944 \cdot MHz$	$CoAdds_{555} = 8$	$SNR\_well_{555} = 570$	$Frames_{555} = 4$	$SNR_{555} = 1140$	$SNR\_req_{555} = 1100$
$\Delta\lambda_{583} = 5 \cdot nm$	$Atten_{583} = 0.55$	$\tau\_integ\_well_{583} = 0.645\ s$	$Readout_{583} = 3.249 \cdot MHz$	$CoAdds_{583} = 8$	$SNR\_well_{583} = 570$	$Frames_{583} = 4$	$SNR_{583} = 1140$	$SNR\_req_{583} = 1100$
$\Delta\lambda_{617} = 5 \cdot nm$	$Atten_{617} = 0.55$	$\tau\_integ\_well_{617} = 0.609\ s$	$Readout_{617} = 3.443 \cdot MHz$	$CoAdds_{617} = 8$	$SNR\_well_{617} = 470$	$Frames_{617} = 6$	$SNR_{617} = 1151$	$SNR\_req_{617} = 1100$
$\Delta\lambda_{625} = 5 \cdot nm$	$Atten_{625} = 0.55$	$\tau\_integ\_well_{625} = 0.608\ s$	$Readout_{625} = 3.452 \cdot MHz$	$CoAdds_{625} = 8$	$SNR\_well_{625} = 457$	$Frames_{625} = 6$	$SNR_{625} = 1119$	$SNR\_req_{625} = 1100$

Si-CCD - FW Radiometer Summary_2

$\Delta\lambda_{640} = 5 \cdot nm$	$Atten_{640} = 0.55$	$\tau\_integ\_well_{640} = 0.606\,s$	$Readout_{640} = 3.462 \cdot MHz$	$CoAdds_{640} = 8$	$SNR\_well_{640} = 443$	$Frames_{640} = 7$	$SNR_{640} = 1172$	$SNR\_req_{640} = 1100$
$\Delta\lambda_{655} = 5 \cdot nm$	$Atten_{655} = 0.55$	$\tau\_integ\_well_{655} = 0.609\,s$	$Readout_{655} = 3.445 \cdot MHz$	$CoAdds_{655} = 8$	$SNR\_well_{655} = 428$	$Frames_{655} = 7$	$SNR_{655} = 1131$	$SNR\_req_{655} = 1100$
$\Delta\lambda_{665} = 5 \cdot nm$	$Atten_{665} = 0.55$	$\tau\_integ\_well_{665} = 0.604\,s$	$Readout_{665} = 3.47 \cdot MHz$	$CoAdds_{665} = 8$	$SNR\_well_{665} = 422$	$Frames_{665} = 7$	$SNR_{665} = 1115$	$SNR\_req_{665} = 1100$
$\Delta\lambda_{678} = 5 \cdot nm$	$Atten_{678} = 0.55$	$\tau\_integ\_well_{678} = 0.6\,s$	$Readout_{678} = 3.496 \cdot MHz$	$CoAdds_{678} = 8$	$SNR\_well_{678} = 414$	$Frames_{678} = 8$	$SNR_{678} = 1170$	$SNR\_req_{678} = 1100$
$\Delta\lambda_{710} = 5 \cdot nm$	$Atten_{710} = 0.55$	$\tau\_integ\_well_{710} = 0.595\,s$	$Readout_{710} = 3.522 \cdot MHz$	$CoAdds_{710} = 8$	$SNR\_well_{710} = 380$	$Frames_{710} = 9$	$SNR_{710} = 1139$	$SNR\_req_{710} = 1100$
$\Delta\lambda_{748} = 10 \cdot nm$	$Atten_{748} = 0.325$	$\tau\_integ\_well_{748} = 0.492\,s$	$Readout_{748} = 4.259 \cdot MHz$	$CoAdds_{748} = 4$	$SNR\_well_{748} = 249$	$Frames_{748} = 8$	$SNR_{748} = 703$	$SNR\_req_{748} = 660$
$\Delta\lambda_{752} = 5 \cdot nm$	$Atten_{752} = 0.55$	$\tau\_integ\_well_{752} = 0.577\,s$	$Readout_{752} = 3.635 \cdot MHz$	$CoAdds_{752} = 4$	$SNR\_well_{752} = 247$	$Frames_{752} = 8$	$SNR_{752} = 698$	$SNR\_req_{752} = 660$
$\Delta\lambda_{760} = 3 \cdot nm$	$Atten_{760} = 0.55$	$\tau\_integ\_well_{760} = 0.949\,s$	$Readout_{760} = 2.211 \cdot MHz$	$CoAdds_{760} = 4$	$SNR\_well_{760} = 243$	$Frames_{760} = 8$	$SNR_{760} = 688$	$SNR\_req_{760} = 660$
$\Delta\lambda_{763} = 3 \cdot nm$	$Atten_{763} = 0.55$	$\tau\_integ\_well_{763} = 0.942\,s$	$Readout_{763} = 2.226 \cdot MHz$	$CoAdds_{763} = 4$	$SNR\_well_{763} = 242$	$Frames_{763} = 8$	$SNR_{763} = 684$	$SNR\_req_{763} = 660$
$\Delta\lambda_{765} = 40 \cdot nm$	$Atten_{765} = 0.075$	$\tau\_integ\_well_{765} = 0.519\,s$	$Readout_{765} = 4.038 \cdot MHz$	$CoAdds_{765} = 4$	$SNR\_well_{765} = 244$	$Frames_{765} = 8$	$SNR_{765} = 691$	$SNR\_req_{765} = 660$
$\Delta\lambda_{820} = 15 \cdot nm$	$Atten_{820} = 0.27$	$\tau\_integ\_well_{820} = 0.523\,s$	$Readout_{820} = 4.013 \cdot MHz$	$CoAdds_{820} = 4$	$SNR\_well_{820} = 222$	$Frames_{820} = 9$	$SNR_{820} = 667$	$SNR\_req_{820} = 660$
$\Delta\lambda_{865} = 40 \cdot nm$	$Atten_{865} = 0.09$	$\tau\_integ\_well_{865} = 0.516\,s$	$Readout_{865} = 4.065 \cdot MHz$	$CoAdds_{865} = 4$	$SNR\_well_{865} = 195$	$Frames_{865} = 12$	$SNR_{865} = 674$	$SNR\_req_{865} = 660$
$\Delta\lambda_{1020} = 40 \cdot nm$	$Atten_{1020} = 0.4$	$\tau\_integ\_well_{1020} = 0.521\,s$	$Readout_{1020} = 4.029 \cdot MHz$	$CoAdds_{1020} = 4$	$SNR\_well_{1020} = 159$	$Frames_{1020} = 10$	$SNR_{1020} = 502$	$SNR\_req_{1020} = 495$

Intermediate Process

$$\text{Aperture\_area} := \frac{\pi}{4}\left(\text{Aperture\_dia}\right)^2 = 490.874\cdot\text{cm}^2$$

$$\text{ster\_Aperture} := \frac{\text{Aperture\_area}}{\text{Orbit\_alt}^2} = 3.83304\times 10^{-17}\cdot\text{sr}$$

$$\text{Etendue} := \text{ster\_Aperture}\cdot\text{GSD}^2 = 5.98913\times 10^{-9}\cdot\text{cm}^2$$

$$\text{Nq} := \frac{\text{Well\_cap}}{2^{\text{AD\_bits}}\cdot\sqrt{12}} = 70.477$$

$$\text{Nq\_si} := \frac{\text{Well\_cap\_si}}{2^{\text{AD\_bits\_si}}\cdot\sqrt{12}} = 8.81$$

$$\text{Noise} := \text{Nr}^2 + \text{Nq}^2 = 14967.1$$

$$\text{Noise\_si} := \text{Nr\_si}^2 + \text{Nq\_si}^2 = 477.6$$

Integration time to avoid well saturation

$Atten_{820} := 1$

Don't need to attenuate throughput on this band

$Margin := 1.1$

$\Delta\lambda_d := \frac{\Delta\lambda_d}{b_d}$

$Opt\_Tx\_mct_d := Opt\_Tx_d \cdot Atten_d$

$CoAdds_d := Bin\_spatial \cdot b_d$

$SNR\_req_d := SNR\_req_d \cdot (Margin)$

$$PEx\_max_d := L\_max_d \cdot Etendue \cdot Opt\_Tx\_mct_d \cdot \frac{d \cdot nm}{h \cdot c} \cdot \Delta\lambda_d \cdot QE_d$$

$$\tau\_integ\_well_d := \frac{Well\_cap}{PEx\_max_d}$$

Determine Number of frame averages for SNR

$$PE\_typ_d := L\_typ_d \cdot Etendue \cdot Opt\_Tx_d \cdot \frac{d \cdot nm}{h \cdot c} \cdot \Delta\lambda_d \cdot QE_d \cdot \tau\_integ\_well_d$$

$$N\_dk_d := ceil\left(I\_dk \cdot \tau\_integ\_well_d\right)$$

$$SNR\_well_d := \sqrt{CoAdds_d} \cdot \frac{PE\_typ_d}{\sqrt{PE\_typ_d + N\_dk_d + Noise}}$$

$$SNR\_ratio_d := \left(\frac{SNR\_req_d}{SNR\_well_d}\right)^2$$

$$Frames_d := ceil\left(SNR\_ratio_d\right)$$

$$SNR_d := SNR\_well_d \cdot \sqrt{Frames_d}$$

GEO CAPE Filter Radiometer (FR)

~ Concept Presentations ~

Electrical Design

C. Paul Earle

Aug 12, 2014

Electrical Architecture
(Baseline, MCT Detector)

Integrated Design Capability / Instrument Design Laboratory

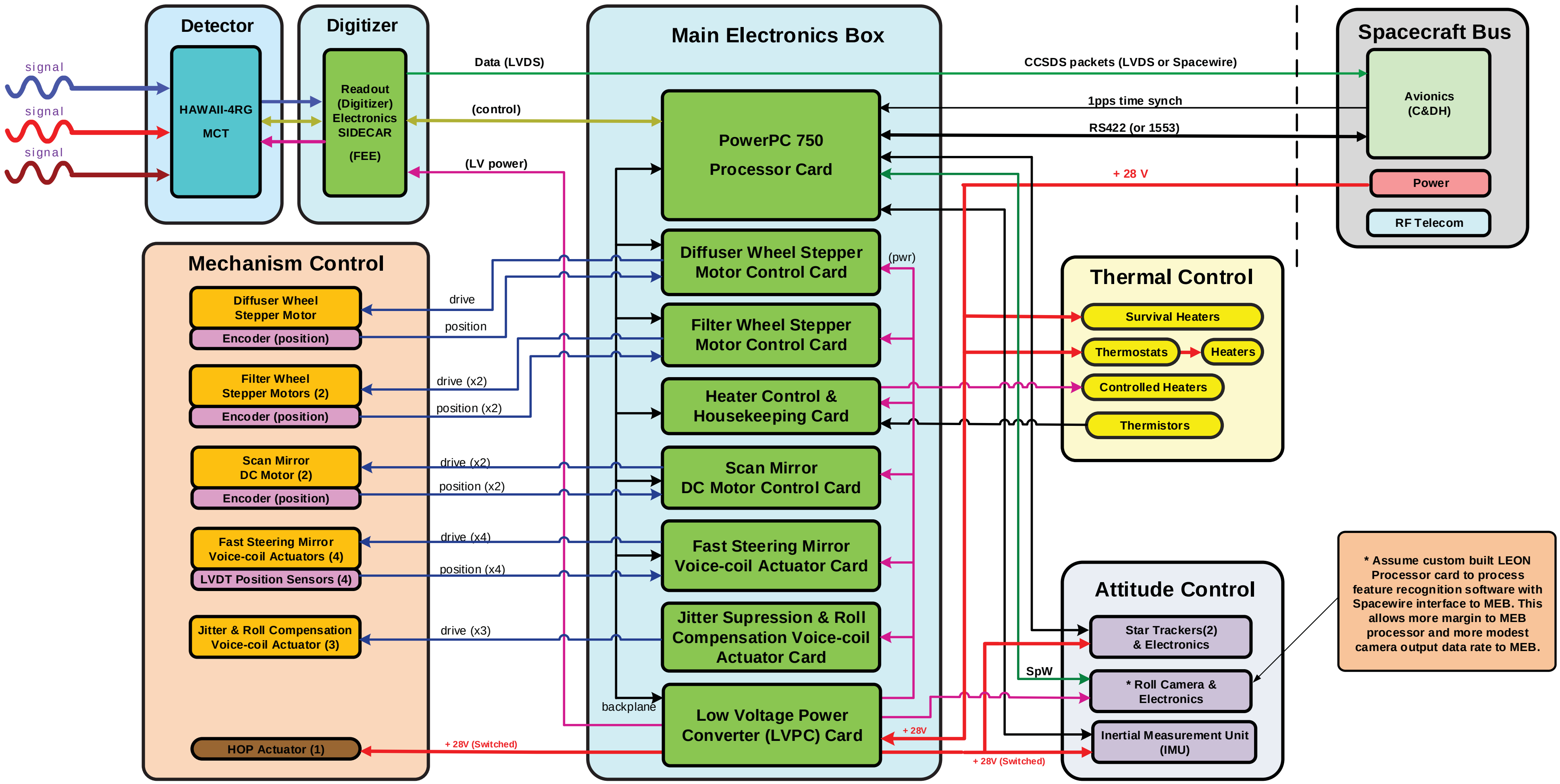
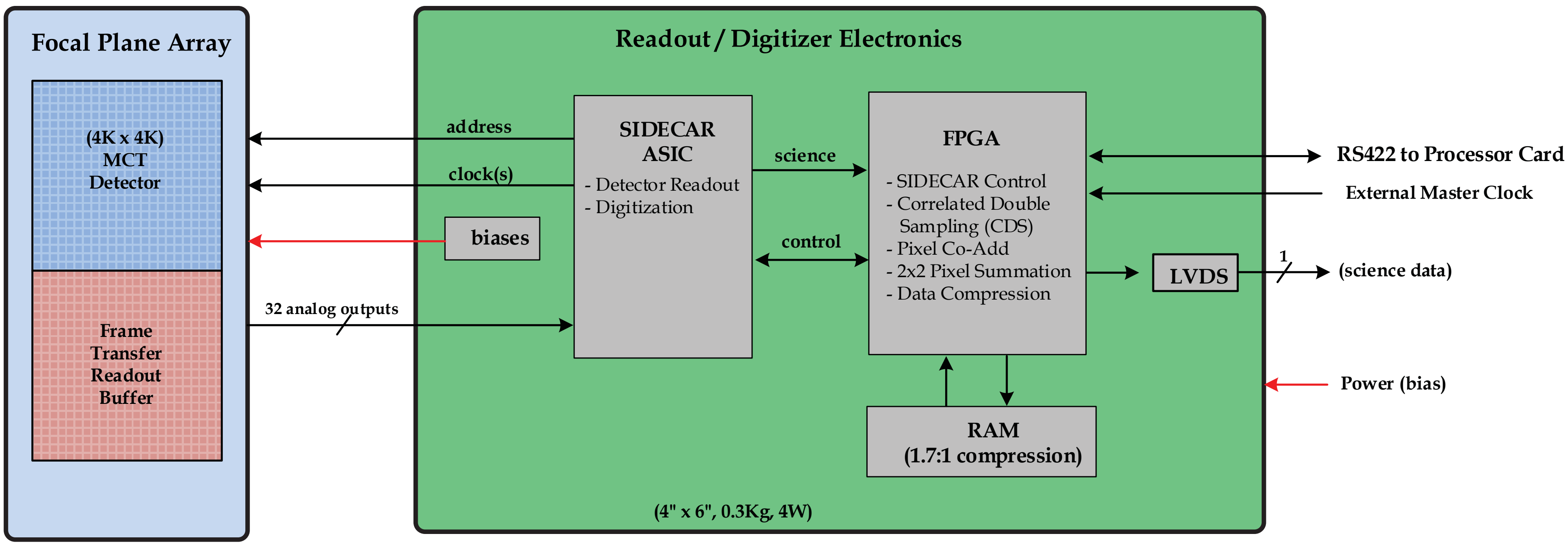


Figure 1.

Detector Readout Electronics

(Baseline, MCT Detector)



Digitizer Box Estimate: (13 x 18 x 8)cm, 1.0Kg (ie. 0.3Kg board total + 0.7Kg Housing), 4W

Figure 2.

Note:
⇒ SIDECAR ADC Sample rate ~ up to 10MHz on each of 32 channels @ 12 bits/sample

Instrument Power Estimates
(Baseline, MCT Detector)

Integrated Design Capability / Instrument Design Laboratory

Instrument & Box Power Calculator

LVPC External Load	Qty	Avg. Power Each (W)	Launch (W)	Standby (W)	Calibration (W)	Science (W)	Survival (W)	
			Power Modes					
Readout/Digitizer Card (s)	1	4.0		0.8	4.0	4.0		
Detectors	1	0.01		0.01	0.01	0.01		
Precision heater(s)	1	1.5		1.5	1.5	1.5		
Diffuser Motor	1	50.0			50.0			50W for 10 sec, 0W otherwise
Diffuser Motor Encoder	1	5.0			5.0			5W for 10 sec, 0W otherwise
Scan Mirror Motor	1	10.3			0.1	0.1		
Scan Mirror Motor Encoder	1	5.0			5.0	5.0		
FSM & Jitter Actuators	7	2.0			14.0	14.0		
LVDT Sensors	4	2.0			8.0	8.0		
Roll Cameras + Electronics	2	11.5			23.0	23.0		
Fliter Wheel Motor & Optical sensors	2	3.8			7.5	7.5		75W @ 10% duty cycle avg
External Load Total:	**22**	**95.1**	**0.0**	**2.3**	**118.1**	**63.1**	**0.0**	
E-Box Circuit Boards								
1. Processor Card	1	15.0		15.0	15.0	15.0		
2. Heater Control Card	1	5.0		5.0	5.0	5.0		
3. Scan DC-Motor Card	1	5.0		5.0	5.0	5.0		
4. Diffuser Stepper Motor Card	1	4.0		4.0	4.0	4.0		
5. FSM Voice-Coil Control	1	4.0		4.0	4.0	4.0		
6. Jitter & Roll Voice-Coil Control	1	4.0		4.0	4.0	4.0		
7. Filter Wheel Motor Drive Card	1	4.0		4.0	4.0	4.0		
Power Converter Efficiency (%)	80							
Power Converter(s)	**1**	**34.0**	**0.0**	**10.8**	**39.8**	**26.0**	**0.0**	
E-Box Total:	**8**	**75.0**	**0.0**	**51.8**	**80.7**	**67.0**	**0.0**	
Direct S/C Bus Load								
IMU	1	24.0		24.0	24.0	24.0		
Star Trackers	1	4.0		4.0	4.0	4.0		
Thermostat Heaters	25	2.8		168.0	70.0	70.0		
Survival Heaters	21	6.7	140.0				140.0	
Direct S/C Bus Load Total:	**52**	**37.5**	**140.0**	**196.0**	**98.0**	**98.0**	**140.0**	
Instrument Total:	**n/a**	**207.5**	**140.0**	**250.1**	**296.8**	**228.1**	**140.0**	S/C Power Bus Requirement

MEB Size & Mass Estimate

Box Size & Mass Calculator

Circuit Boards	Length (x)	Width (z)	Mass each	Qty	Mass (Kg)
Board Dimensions (inches)	8	6	0.50	7	
(cm)	20	15			3.50
Power Supply Card	"	"	0.75	1	0.75
Backplane (inches)	6	8	0.50	1	
(cm)	15	20			0.50
				Board Mass Total:	4.75
Housing	**Depth (x)**	**Height (z)**	**Width (y)**	**Qty**	
Box Dimensions (inches)	9	7	9	1	
(cm)	23	18	23		
Box Wall Thickness (mm)	2.5	mm			
Material (Aluminum) Density	2,700	Kg/m^3			
				Housing Mass :	1.85
				Box Total:	6.60

MEB Mass & Power Summary

E-Box Boards (Internal Load)	Qty	Masss (Kg)	Watts (W)	Description	% Analog / Digital	TRL
1. Processor Card	1	0.5	15.0	Custom Design	5/90	6
2. Heater Control Card	1	0.5	5.0	Custom Design	75/20	6
3. Scan DC-Motor Card	1	0.5	5.0	Custom Design	75/20	6
4. Diffuser Stepper Motor Card	1	0.5	4.0	Custom Design	75/20	6
5. FSM Voice-Coil Control	1	0.5	4.0	Custom Design	75/20	6
6. Jitter & Roll Voice-Coil Control	1	0.5	4.0	Custom Design	75/20	6
7. Filter Wheel Motor Drive Card	1	0.5	4.0	Custom Design	75/20	6
8. Power Converter(s)	1	0.7	26.0	assume 80% efficiency	90/5	6
Backplane	-	0.5	-	passive	-	6
Housing:	-	1.8	-	Aluminum (2.5mm)	-	7
MEB Totals: (Mass & Power):		**6.6**	**67.0**			

MEB Box size: (23 x 18 x 23)cm, 6.6Kg (ie. 4.7Kg board total + 1.9Kg Housing)

SIDECAR Digitizer Box Summary
(Baseline, MCT Detector)

FEE Size & Mass Estimate

Circuit Boards	Length (x)	Width (z)	Mass each	Qty	Mass (Kg)
Board Dimensions (inches)	4	6	0.25	1	
(cm)	10	15			0.25
				Board Mass Total:	0.25
Housing	**Depth (x)**	**Height (z)**	**Width (y)**	**Qty**	
Box Dimensions (inches)	5	7	3	1	
(cm)	13	18	8		
Box Wall Thickness (mm)	2.5	mm			
Material (Aluminum) Density	2,700	Kg/m^3			
				Housing Mass :	0.64
				Box Total:	0.89

FEE Mass & Power Summary

FEE	Qty	Mass (Kg)	Power (W)	Description	% Analog / Digital	TRL
Readout Cards	1	0.25	4.0	FPGA control	50/45	6
Housing:	1	0.64	-	Aluminum (2.5mm)	-	7
Box Totals: (Mass & Power):		0.89	4.0			

Digitizer Box size: (13 x 18 x 8)cm, 0.9Kg (ie. 0.3Kg board total + 0.6Kg Housing)

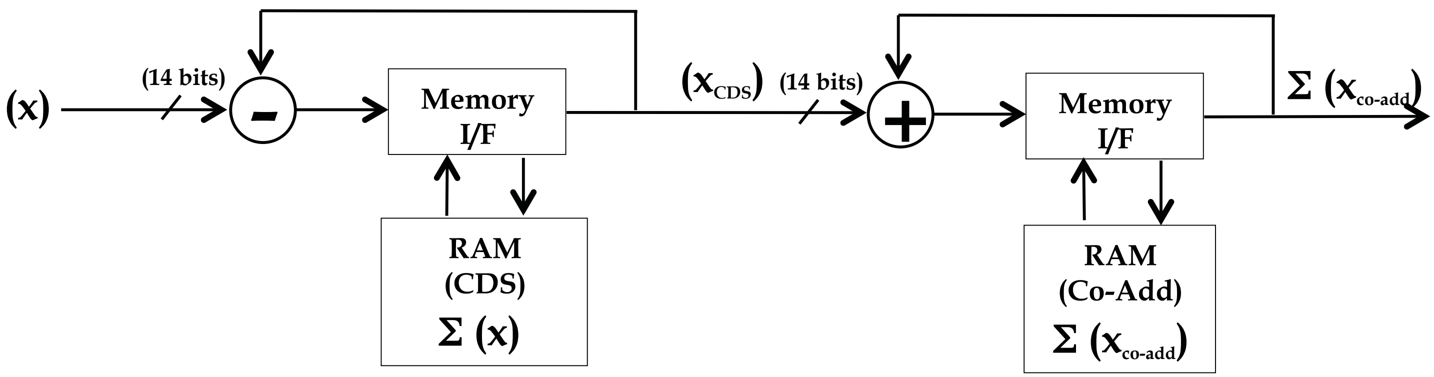
Detector Readout / Data Rate
(Baseline, MCT Detector)

Detector Assumptions
- 1(4K x 4K) MCT Detector Array, 32 taps, up to 10MHz sample rate @12 bits/pix resolution
- Perform Correlated Double Sampling (CDS) on each pixel readout and 2x2 pixel summation

Filter # (band)	Integration Period (sec)	Number of Reads (Frames)	Total Integration Time (sec)	CDS Pixel Digitization Rate (MHz)	CDS Tap Readout Rate (Mbps)	Frame Co-Add Data Rate (Mbps)	(2 x 2)Pixel Aggregation Data Rate	1.7:1 Compressed Data Rate (Mbps)	# bands	Downlink Data Rate (Mbps)
1	1.321	2	2.642	0.7	8.9	76.7	22.1	**13.0**	1	**13.0**
2	1.485	2	2.970	0.7	7.9	68.8	19.8	**11.7**	1	**11.7**
3	2.510	1	2.510	0.4	4.6	74.3	21.7	**12.7**	2	**25.5**
4	1.541	1	1.541	0.6	7.2	115.6	33.7	**19.8**	2	**39.7**
5	1.110	1	1.110	0.8	9.6	153.7	44.8	**26.4**	2	**52.7**
6	1.063	1	1.063	0.8	10.0	159.4	46.5	**27.3**	2	**54.7**
7	1.037	1	1.037	0.8	10.2	162.8	47.5	**27.9**	2	**55.8**
8	1.062	2	2.124	0.9	10.8	93.8	27.1	**15.9**	2	**31.8**
9	1.024	2	2.048	0.9	11.2	97.0	28.0	**16.5**	2	**32.9**
10	0.982	2	1.964	1.0	11.6	100.8	29.1	**17.1**	2	**34.2**
11	0.909	2	1.818	1.0	12.5	108.1	31.2	**18.3**	2	**36.7**
12	0.853	2	1.706	1.1	13.2	114.4	33.0	**19.4**	2	**38.8**
13	0.857	3	2.571	1.1	13.6	84.8	24.2	**14.2**	2	**28.5**
14	0.824	3	2.472	1.2	14.1	87.9	25.1	**14.8**	2	**29.5**
15	0.795	4	3.180	1.2	14.9	69.5	19.9	**11.7**	2	**23.4**
16	0.802	4	3.208	1.2	14.8	68.9	19.7	**11.6**	2	**23.2**
17	0.789	4	3.156	1.2	15.0	70.0	20.0	**11.8**	2	**23.5**
18	0.793	5	3.965	1.3	15.1	56.4	16.1	**9.5**	2	**19.0**
19	0.796	5	3.980	1.3	15.1	56.2	16.1	**9.4**	2	**18.9**
20	0.799	5	3.995	1.2	15.0	56.0	16.0	**9.4**	2	**18.8**
21	0.802	6	4.812	1.3	15.1	50.2	14.2	**8.4**	2	**16.7**
22	0.400	6	2.400	2.4	29.0	96.8	27.4	**16.1**	1	**16.1**
23	0.804	6	4.824	1.3	15.0	50.1	14.2	**8.3**	1	**8.3**
24	1.322	6	7.932	0.8	9.3	30.9	8.8	**5.2**	1	**5.2**
25	1.313	6	7.878	0.8	9.3	31.2	8.8	**5.2**	1	**5.2**
26	0.240	6	1.440	3.8	46.0	153.5	43.5	**25.6**	1	**25.6**
27	0.264	7	1.848	3.6	43.0	122.9	34.8	**20.5**	1	**20.5**
28	0.256	10	2.560	3.8	45.6	91.2	25.8	**15.2**	1	**15.2**
29	0.251	10	2.510	3.9	46.4	92.9	26.3	**15.5**	1	**15.5**
30	0.316	5	1.580	2.9	35.3	132.0	37.7	**22.2**	1	**22.2**
31	0.349	3	1.047	2.5	30.3	174.9	50.5	**29.7**	1	**29.7**
Avg:	**0.893**	**4.0**	**2.835**	**1.5**	**18.1**	**93.6**	**26.9**	15.8	50	15.9

Correlated Double Sampling & Co-Add

FPGA Pixel Processing Algorithms: (CDS, Frame Co-Add, 2x2 Pixel summation)



Example:
(14 + $\log_2$N) bits/pix => (14+ 1)bits/pix = 15bits/pix (for two co-added pixels)

Key
N = Number of co-added frames.
n = co-add bit overhead = $\log_2$N
ie.
n=1 for N=2 (for 1.7sec integration)
n=2 for N=4
n=4 for N=10
n=5 for N=20
n=6 for N=48

Figure 3.

Mechanical Layout

Dimensions used as *basis for harness length & Mass estimates*

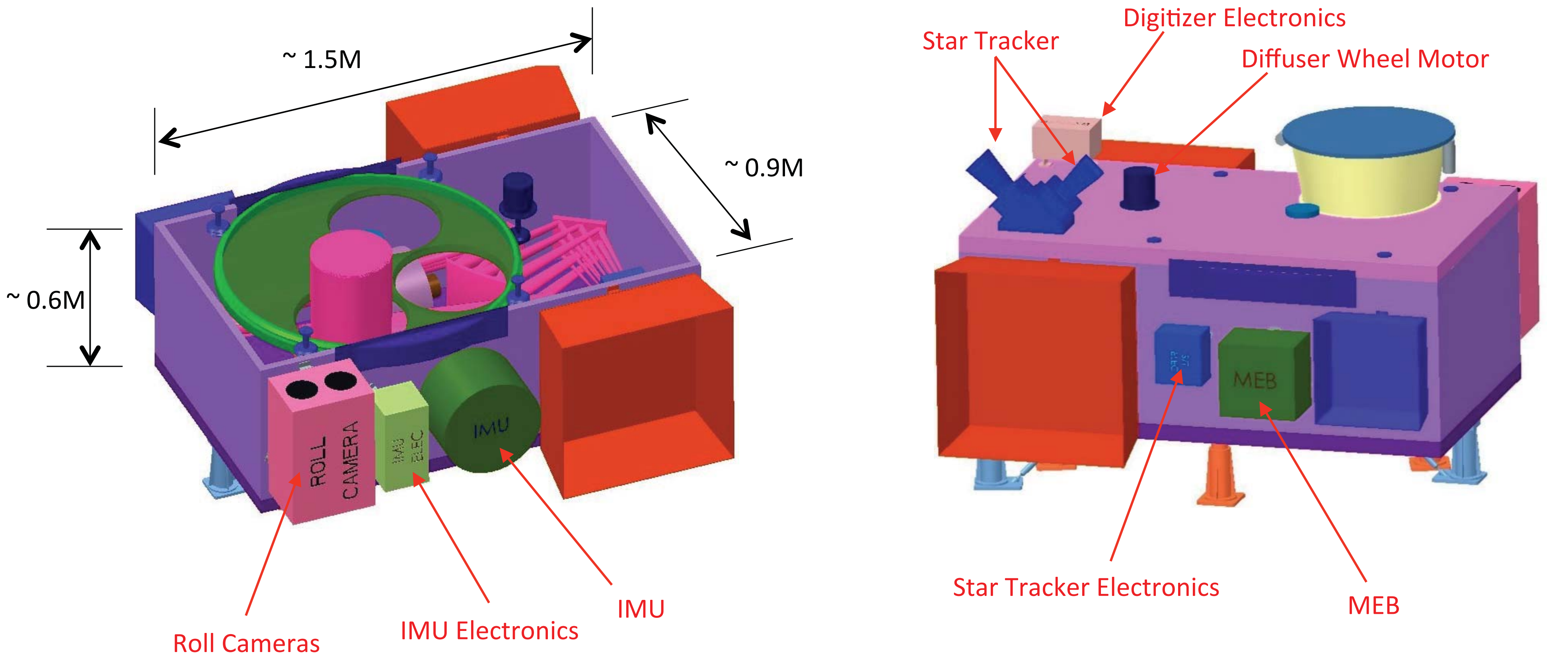


Figure 4.

Instrument Harness Mass Estimate
(Baseline, MCT Detector)

Integrated Design Capability / Instrument Design Laboratory

Harness Mass Calculator

Harness ID		Harness Parameters						Connector & Backshell		Line
Source (From)	Destination (To)	Wire Type (Select)	Description (Table lookup)	Qty	Length (m)	Density (g/m)	Mass (g)	Type (Select)	Mass (g) (2x)	Totals (g)
Digitizer	MCT Detector Assembly	Single-24AWG	M22759/33-24-0	50	0.5	3.25	81.20	51P (MDM)	40.00	121.20
Digitizer	MEB	Power, LVDS	(20, 24)AWG	4	0.5	27.23	54.46	15P (MDM)	32.00	86.46
MEB	Filter Wheel Motors + sensors (2)	TP-22AWG	M27500-22SC2U00	12	3.0	10.50	377.95	15P (MDM)	32.00	409.95
MEB	Scan Mirror Assy + Enc	TSP-22AWG	M27500-22SC2S23	15	3.0	22.97	1033.46	44P (HD)	62.00	1095.46
MEB	FSM Voice Coils (4) + LVDT	TSP-22AWG	M27500-22SC2S23	8	3.0	22.97	551.18	25P (MDM)	34.40	585.58
MEB	Diffuser Wheel Motor Assy+ Enc	TSP-22AWG	M27500-22SC2S23	15	3.0	22.97	1033.46	44P (HD)	62.00	1095.46
MEB	Jitter/Roll Voice Coils (3)	TSP-22AWG	M27500-22SC2S23	3	3.0	22.97	206.69	9P (MDM)	29.20	235.89
MEB	Launch Locks (7)	TP-20AWG	M27500-20SC2U00	7	3.0	16.40	344.49	21P (MDM)	33.20	377.69
MEB	Star Tracker Electronics	Power, RS422	(12, 24)AWG	1	2.5	109.55	273.87	9P (MDM)	29.20	303.07
MEB	IMU Electronics	Power, RS422	(12, 24)AWG	1	2.5	109.55	273.87	9P (MDM)	29.20	303.07
MEB	Roll Camera Electronics	Power, SpW	(20, 24)AWG	1	2.5	88.25	220.64	9P (MDM)	29.20	249.84
MEB	Precision Heaters (1)	TP-20AWG	M27500-20SC2U00	2	1.5	16.40	49.21	15P (MDM)	32.00	81.21
MEB	Thermostat / Survival Heaters (15)	TP-20AWG	M27500-20SC2U00	182	2.0	16.40	5971.13	37P (MDM)	40.00	6011.13
MEB	Temperature Sensors (20)	TSP-24AWG	M27500-24SC2S23	44	2.0	18.37	1616.80	51P (MDM)	40.00	1656.80
MEB	SCIF	Pwr, RS422, 1553, 1pps	(12, 24, 24,24)AWG	1	2.0	151.54	303.08	15P (MDM)	32.00	335.08
Digitizer	SCIF (3)	SpaceWire (SpW)	9 wires (4 TSPs + GND)	3	2.0	74.80	448.82	37P (MDM)	40.00	488.82
						Total:	12840.32	-	596.40	13436.72 g
									Total:	13.44 Kg
									+ 5% misc:	14.11 Kg

Note:

- This mass estimate is the current best estimate based on this point design, and represents ~6% of the total instrument mass. Historically, flight instruments have been delivered with the harness mass totaling 7-12% of the total instrument mass, so the customer may choose to book keep a more conservative estimate of harness mass until a more detailed electrical assessment can be performed.
- 5% misc added for tie-downs, ground straps, and insulation

Electrical Architecture
(DeScope Option, Si CCD Detectors)

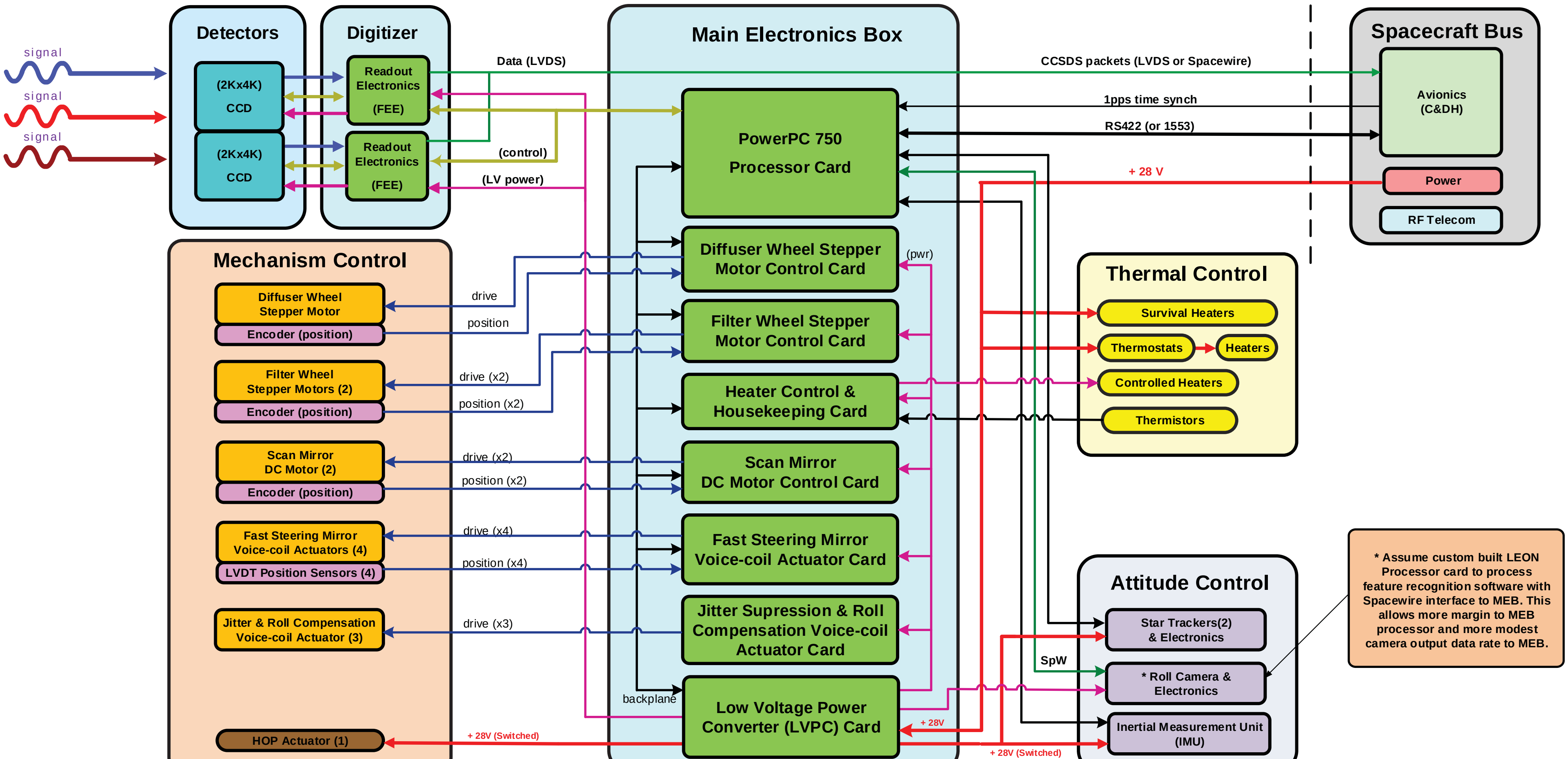
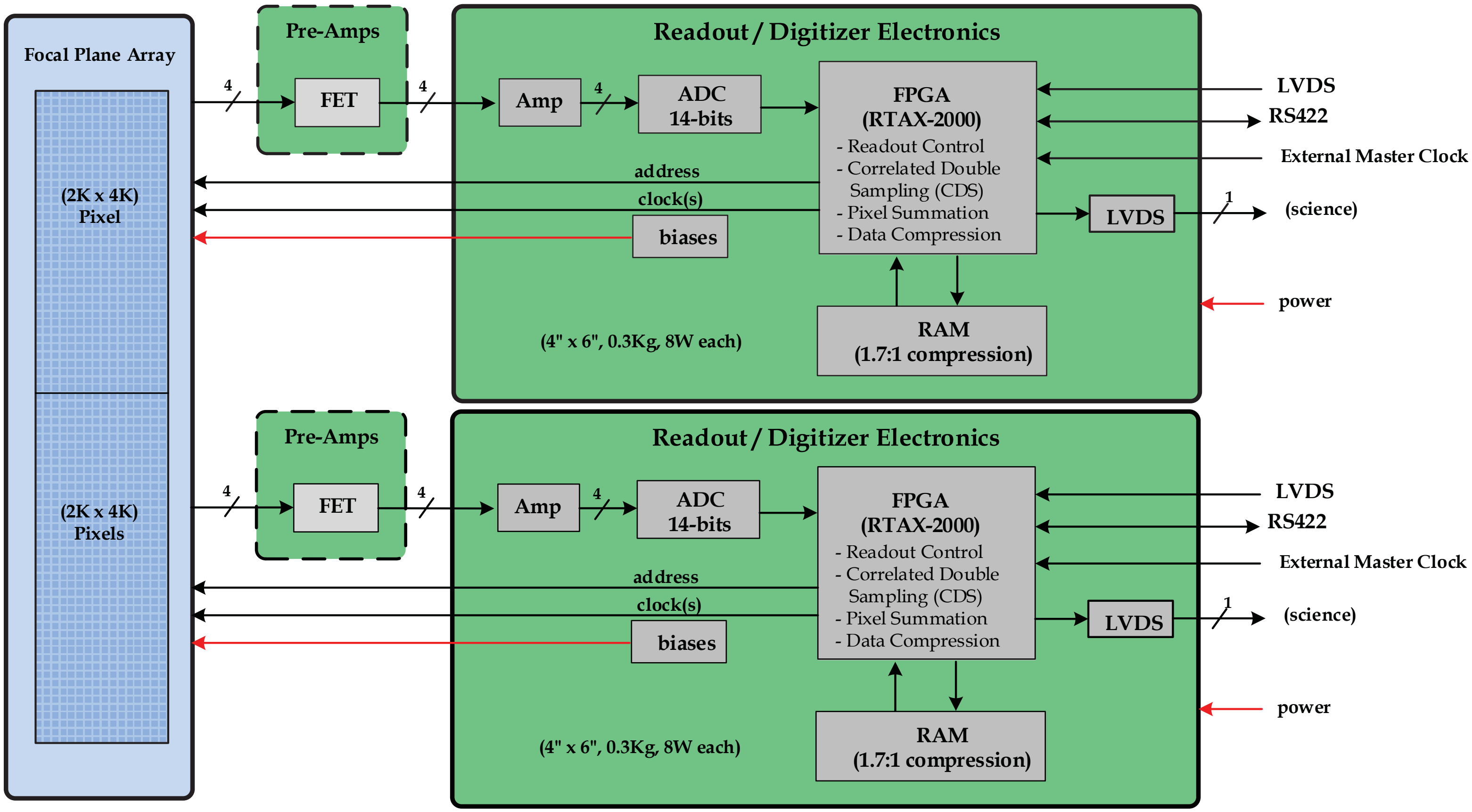


Figure 1b.

Detector Readout (Digitizer)
(Descope Option, Si CCD Detectors)



Box Estimate: (13 x 18 x 15)cm, 2.0Kg (ie. 1.0Kg board total + 1.0Kg Housing), 32W

Figure 2b.

Note:
⇒ ADC Sample rate ~ up to 155MHz on each of 4channels @ 14 bits/sample, ADC14155QML-SP, TI
⇒ Two readout Cards per (2kx4K) pixels (ie. 4 readout Cards total housed in a single Digitizer Box)

Instrument Power Estimates
(Descope Option, Si CCD Detectors)

Instrument & Box Power Calculator

		Avg. Power	Power Modes					
		Each	Launch	Standby	Calibration	Science	Survival	
LVPC External Load	Qty	(W)	(W)	(W)	(W)	(W)	(W)	
Readout/Digitizer Card (s)	1	8.0		1.6	8.0	8.0		
Detectors	1	4.00		4.00	4.00	4.00		
Precision heater(s)	1	2.0		2.0	2.0	2.0		
Diffuser Motor	1	50.0			50.0			50W for 10 sec, 0W otherwise
Diffuser Motor Encoder	1	5.0			5.0			5W for 10 sec, 0W otherwise
Scan Mirror Motor	1	10.3			0.1	0.1		
Scan Mirror Motor Encoder	1	5.0			5.0	5.0		
FSM & Jitter Actuators	7	2.0			14.0	14.0		
LVDT Sensors	4	2.0			8.0	8.0		
Roll Cameras + Electronics	2	11.5			23.0	23.0		
Fliter Wheel Motor & Optical sensors	2	3.8			7.5	7.5		75W @ 10% duty cycle avg
External Load Total:	**22**	**103.6**	**0.0**	**7.6**	**126.6**	**71.6**	**0.0**	
E-Box Circuit Boards								
1. Processor Card	1	15.0		15.0	15.0	15.0		
2. Heater Control Card	1	5.0		5.0	5.0	5.0		
3. Scan DC-Motor Card	1	5.0		5.0	5.0	5.0		
4. Diffuser Stepper Motor Card	1	4.0		4.0	4.0	4.0		
5. FSM Voice-Coil Control	1	4.0		4.0	4.0	4.0		
6. Jitter & Roll Voice-Coil Control	1	4.0		4.0	4.0	4.0		
7. Filter Wheel Motor Drive Card	1	4.0		4.0	4.0	4.0		
Power Converter Efficiency (%)	80							
Power Converter(s)	**1**	**36.1**	**0.0**	**12.1**	**41.9**	**28.1**	**0.0**	
E-Box Total:	**8**	**77.1**	**0.0**	**53.1**	**82.8**	**69.1**	**0.0**	
Direct S/C Bus Load								
IMU	1	24.0		24.0	24.0	24.0		
Star Trackers	1	4.0		4.0	4.0	4.0		
Thermostat Heaters	25	2.8		168.0	70.0	70.0		
Survival Heaters	21	6.7	140.0				140.0	
Direct S/C Bus Load Total:	**52**	**37.5**	**140.0**	**196.0**	**98.0**	**98.0**	**140.0**	
Instrument Total:	**n/a**	**218.1**	**140.0**	**256.7**	**307.4**	**238.7**	**140.0**	S/C Power Bus Requirement

CCD Digitizer Box Summary
(Descope Option, Si CCD Detector)

FEE (Digitizer) Box Size

Circuit Boards	Length (x)	Width (z)	Mass each	Qty	Mass (Kg)
Board Dimensions (inches)	4	6	0.25	4	1.00
(cm)	10	15			
				Board Mass Total:	1.00
Housing	**Depth (x)**	**Height (z)**	**Width (y)**	**Qty**	
Box Dimensions (inches)	5	7	6	1	
(cm)	13	18	15		
Box Wall Thickness (mm)	2.5	mm			
Material (Aluminum) Density	2,700	Kg/m^3			
				Housing Mass :	0.96
				Box Total:	1.96

FEE (Digitizer) Mass & Power Summary

FEE	Qty	Mass (Kg)	Power (W)	Description	% Analog / Digital	TRL
Readout Cards	4	1.00	32.0	FPGA control	50/45	6
Housing:	1	0.96	-	Aluminum (2.5mm)	-	7
Box Totals: (Mass & Power):		1.96	32.0			

Digitizer Box size: (13 x 18 x 15)cm, 2.0Kg (ie. 1.0Kg board total + 1.0Kg Housing)

Detector Readout / Data Rate

(DeScope Option, Si CDD Detector)

Detector Assumptions

- 1(4K x 4K) CCD Detector Array, 16 taps, up to 155MHz sample rate @14 bits/pix resolution
- Perform Correlated Double Sampling (CDS) on each pixel readout and 2x2 pixel summation

Filter # (band)	Integration Period (sec)	Number of Reads (Frames)	Total Integration Time (sec)	CDS Pixel Digitization Rate (MHz)	CDS Tap Readout Rate (Mbps)	Frame Co-Add Data Rate (Mbps)	(2 x 2)Pixel Aggregation Data Rate	1.7:1 Compressed Data Rate (Mbps)	# bands	Downlink Data Rate (Mbps)
1	0.599	3	1.797	3.2	44.1	126.0	35.7	**21.0**	1	**21.0**
2	0.730	3	2.190	2.6	36.9	105.3	29.8	**17.5**	1	**17.5**
3	1.178	2	2.356	1.6	23.0	98.5	27.9	**16.4**	2	**32.8**
4	0.699	2	1.398	2.6	36.7	157.5	44.6	**26.2**	2	**52.5**
5	0.508	2	1.016	3.4	48.3	207.0	58.6	**34.5**	2	**69.0**
6	0.492	2	0.984	3.5	49.6	212.5	60.2	**35.4**	2	**70.8**
7	0.491	2	0.982	3.5	49.7	212.9	60.3	**35.5**	2	**71.0**
8	0.502	2	1.004	3.5	48.8	209.0	59.2	**34.8**	2	**69.7**
9	0.491	3	1.473	3.8	52.6	150.4	42.6	**25.1**	2	**50.1**
10	0.835	3	2.505	2.3	32.6	93.0	26.4	**15.5**	2	**31.0**
11	0.774	3	2.322	2.5	34.9	99.8	28.3	**16.6**	2	**33.3**
12	0.717	4	2.868	2.7	38.3	87.5	24.6	**14.5**	2	**29.0**
13	0.712	4	2.848	2.8	38.5	88.1	24.8	**14.6**	2	**29.1**
14	0.645	4	2.580	3.0	42.2	96.6	27.2	**16.0**	2	**31.9**
15	0.609	6	3.654	3.3	45.7	74.0	20.7	**12.2**	2	**24.3**
16	0.608	6	3.648	3.3	45.8	74.1	20.7	**12.2**	2	**24.4**
17	0.606	7	4.242	3.3	46.3	64.2	17.9	**10.6**	2	**21.1**
18	0.609	7	4.263	3.3	46.0	63.9	17.9	**10.5**	2	**21.0**
19	0.604	7	4.228	3.3	46.4	64.4	18.0	**10.6**	2	**21.2**
20	0.600	8	4.800	3.4	47.0	57.0	15.9	**9.4**	2	**18.8**
21	0.595	9	5.355	3.4	47.6	51.3	14.3	**8.4**	2	**16.9**
22	0.492	8	3.936	4.1	56.8	69.0	19.3	**11.3**	1	**11.3**
23	0.577	8	4.616	3.5	48.8	59.2	16.5	**9.7**	1	**9.7**
24	0.949	8	7.592	2.2	30.1	36.6	10.2	**6.0**	1	**6.0**
25	0.942	8	7.536	2.2	30.4	36.9	10.3	**6.1**	1	**6.1**
26	0.519	8	4.152	3.9	54.0	65.5	18.3	**10.8**	1	**10.8**
27	0.523	9	4.707	3.8	53.8	58.1	16.2	**9.6**	1	**9.6**
28	0.516	12	6.192	3.9	55.1	47.2	13.1	**7.7**	1	**7.7**
29	0.521	10	5.210	3.9	54.3	55.8	15.5	**9.1**	1	**9.1**
Avg:	**0.643**	**5.5**	**3.464**	**3.2**	**44.3**	**97.3**	**27.4**	16.1	48	17.2

Instrument Harness Mass Estimate
(DeScope Option, Si CCD Detector)

Integrated Design Capability / Instrument Design Laboratory

Harness Mass Calculator

Harness ID		Harness Parameters						Connector & Backshell		Line Totals
Source (From)	Destination (To)	Wire Type (Select)	Description (Table lookup)	Qty	Length (m)	Density (g/m)	Mass (g)	Type (Select)	Mass (g) (2x)	(g)
Digitizer	CCD Detector Assembly	Single-24AWG	M22759/33-24-0	40	0.5	3.25	64.96	51P (MDM)	40.00	104.96
Digitizer	MEB	Power, LVDS	(20, 24)AWG	4	0.5	27.23	54.46	15P (MDM)	32.00	86.46
MEB	Filter Wheel Motors + sensors (2)	TP-22AWG	M27500-22SC2U00	12	3.0	10.50	377.95	15P (MDM)	32.00	409.95
MEB	Scan Mirror Assy + Enc	TSP-22AWG	M27500-22SC2S23	15	3.0	22.97	1033.46	44P (HD)	62.00	1095.46
MEB	FSM Voice Coils (4) + LVDT	TSP-22AWG	M27500-22SC2S23	8	3.0	22.97	551.18	25P (MDM)	34.40	585.58
MEB	Diffuser Wheel Motor Assy+ Enc	TSP-22AWG	M27500-22SC2S23	15	3.0	22.97	1033.46	44P (HD)	62.00	1095.46
MEB	Jitter/Roll Voice Coils (3)	TSP-22AWG	M27500-22SC2S23	3	3.0	22.97	206.69	9P (MDM)	29.20	235.89
MEB	Launch Locks (7)	TP-20AWG	M27500-20SC2U00	7	3.0	16.40	344.49	21P (MDM)	33.20	377.69
MEB	Star Tracker Electronics	Power, RS422	(12, 24)AWG	1	2.5	109.55	273.87	9P (MDM)	29.20	303.07
MEB	IMU Electronics	Power, RS422	(12, 24)AWG	1	2.5	109.55	273.87	9P (MDM)	29.20	303.07
MEB	Roll Camera Electronics	Power, SpW	(20, 24)AWG	1	2.5	88.25	220.64	9P (MDM)	29.20	249.84
MEB	Precision Heaters (1)	TP-20AWG	M27500-20SC2U00	2	1.5	16.40	49.21	15P (MDM)	32.00	81.21
MEB	Thermostat / Survival Heaters (15)	TP-20AWG	M27500-20SC2U00	182	2.0	16.40	5971.13	37P (MDM)	40.00	6011.13
MEB	Temperature Sensors (20)	TSP-24AWG	M27500-24SC2S23	44	2.0	18.37	1616.80	51P (MDM)	40.00	1656.80
MEB	SCIF	Pwr, RS422, 1553, 1pps	(12, 24, 24,24)AWG	1	2.0	151.54	303.08	15P (MDM)	32.00	335.08
Digitizer	SCIF (3)	SpaceWire (SpW)	9 wires (4 TSPs + GND)	3	2.0	74.80	448.82	37P (MDM)	40.00	488.82
						Total:	12824.08	-	596.40	13420.48 g
									Total:	13.42 Kg
									+ 5% misc:	14.09 Kg

Note:

- This mass estimate is the current best estimate based on this point design, and represents ~6% of the total instrument mass. Historically, flight instruments have been delivered with the harness mass totaling 7-12% of the total instrument mass, so the customer may choose to book keep a more conservative estimate of harness mass until a more detailed electrical assessment can be performed.
- 5% misc added for tie-downs, ground straps, and insulation

Baseline vs. Alternate Configuration

Resources	Baseline (MCT)	Descope Option (Si-CCD)
Mass (kg)	21.6	22.7
Difference (kg):	0	**1.1**
Percentage (%):	0.0	5.1
Power (Watts)	318.1	360.6
Difference (Watts):	0	**42.5**
Percentage (%):	0.0	13.4
Data Rate (Mbps)	15.9	17.4
Difference (Mbps):	0	**-1.5**
Percentage (%):	0.0	-9.4

Issues / Conclusion / Summary

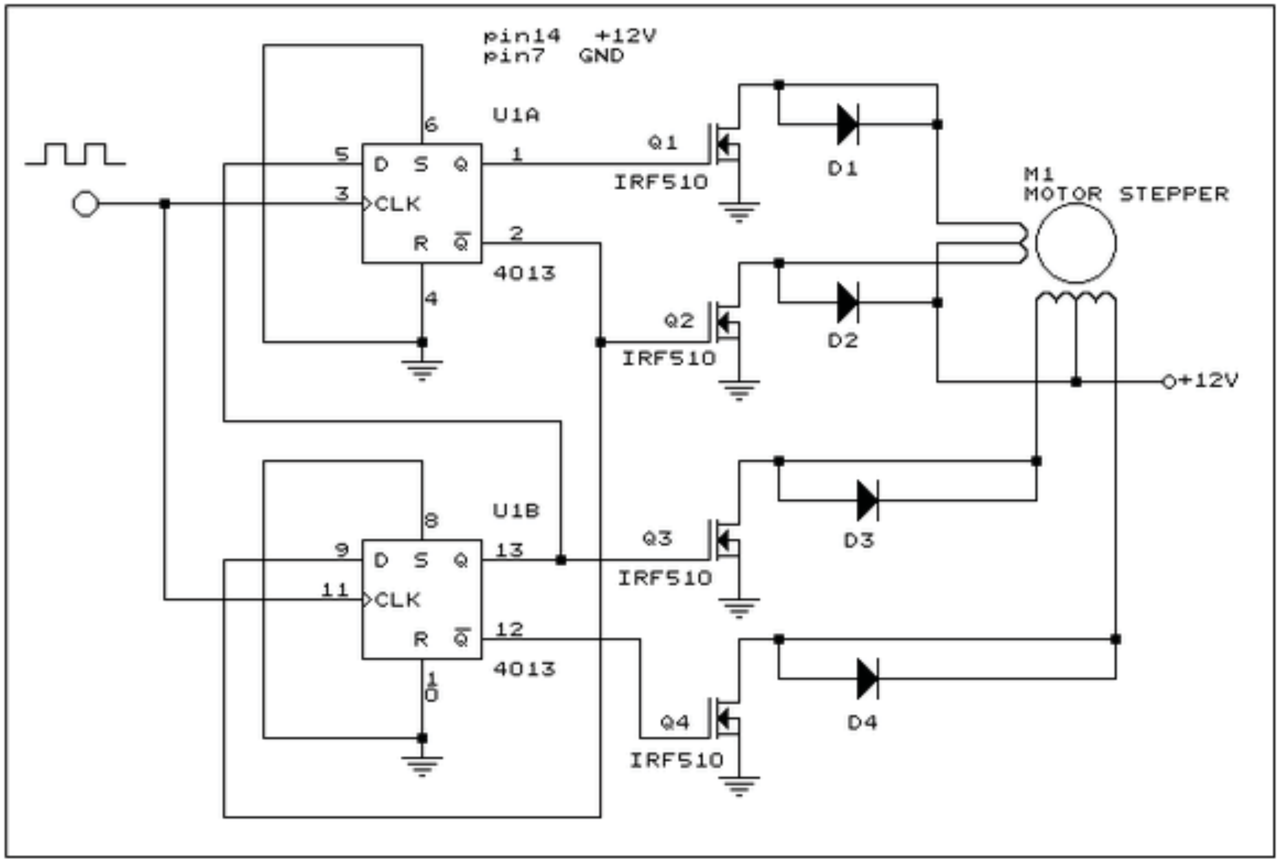
- No low TRL items or concerns. All TRLs are ≥ 6.
- The baseline design assumes single-string electronics, except for heaters which are redundant.
- The main processor is dedicated to ACS data processing with input from the IMU, Star Tracker, Roll Cameras, and closed-loop PID heater control, while the FPGAs are used for mechanism control, pixel processing algorithms and data compression.
- A LEON processor card was added to the Roll Camera electronics to "pre-process" the scene identification logic to minimize bandwidth to the MEB and to increase the % utilization margin on MEB PowerPC processor at this stage of the design.
- Data Compression is assumed @ ~ 1.7:1 to reduce downlink bandwidth/transponder requirements (15.2Mbps) and hence cost. Data volume generated over 16 hours of operation is ~ 875.5Gbits.
- Baseline design is best estimate of actual mass, power, and data rate (ie. No margins or contingency were added).

Backup Slides

(Electrical Design Estimates)

Sample Stepper Motor Controller Circuit

(Notional: Basis of Estimate)



(Assume 4 circuits on 1 Card, 4W)

Figure 9.

Closed-Loop PID Heater Control & H/K

(Notional: Basis of Estimate)

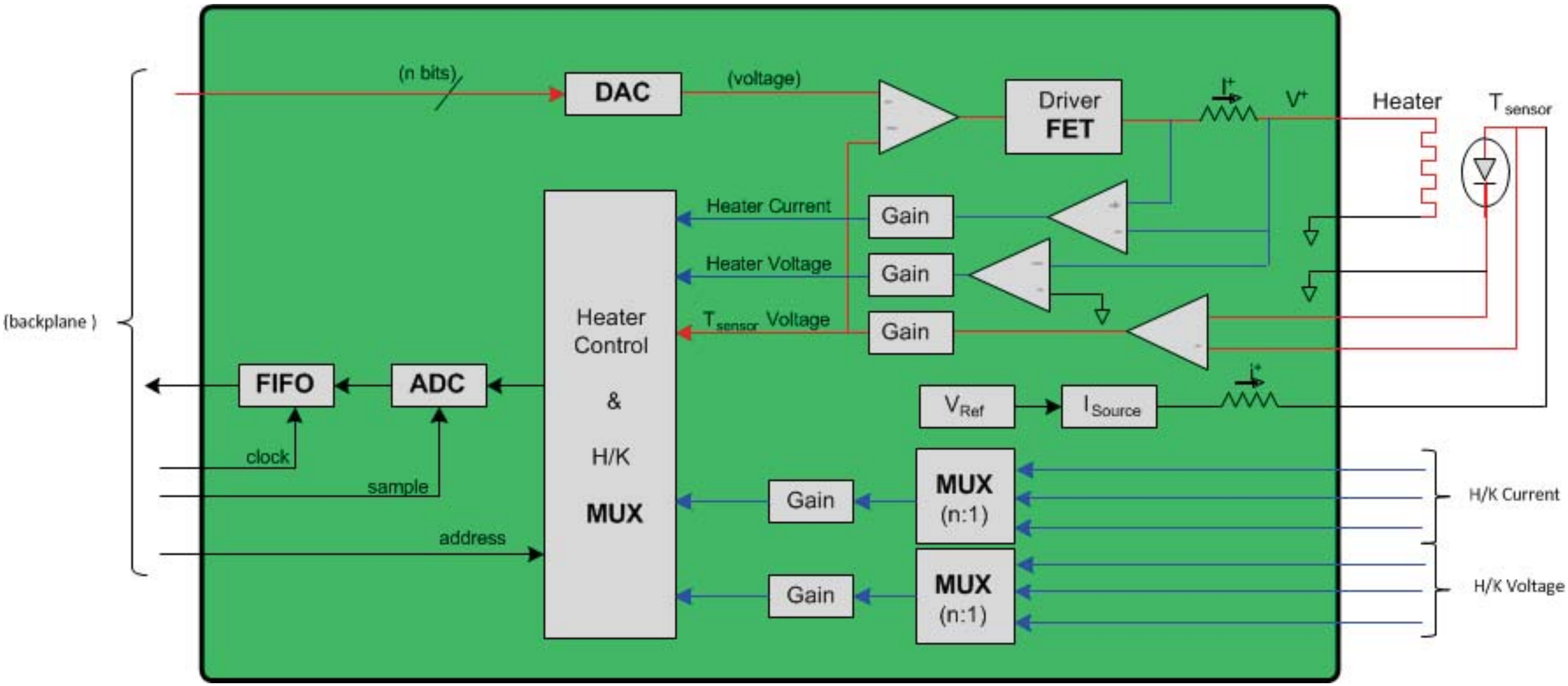
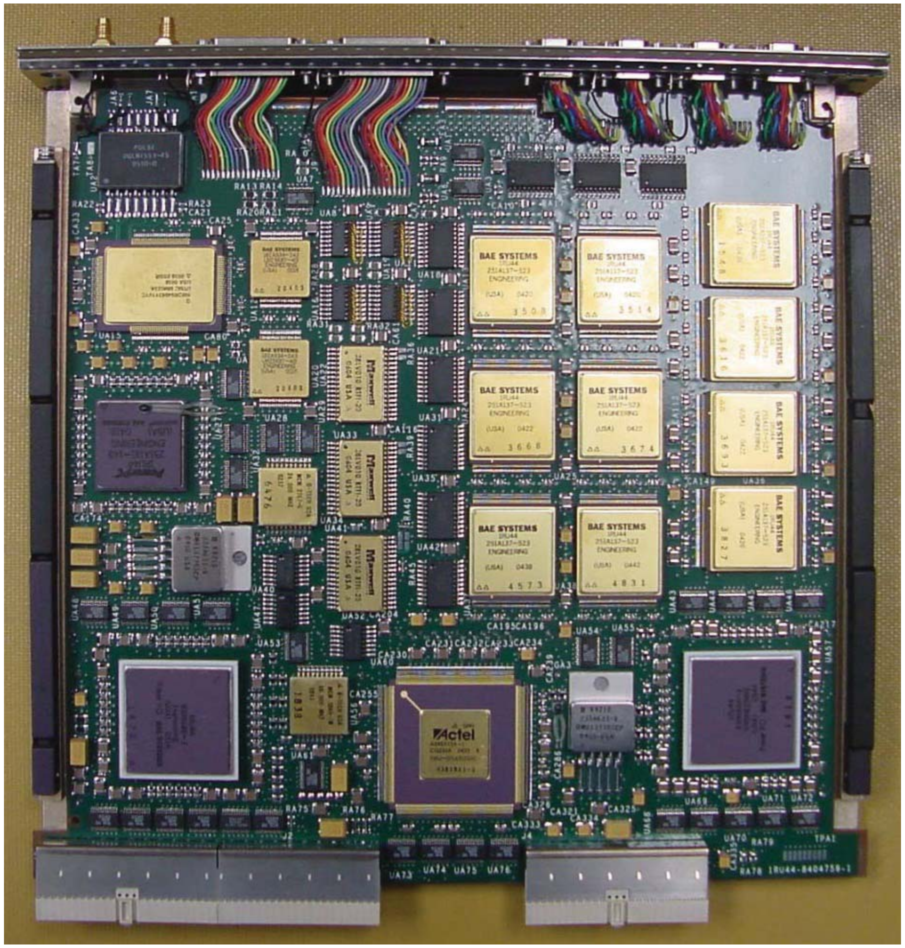


Figure 10.

Single Board Computer



6U-220mm Front Side View

BAE SYSTEMS

6U CompactPCI Single Board Computer

–A Double-sided 6U CompactPCI Single Board Computer
–Populated with RAD750 capable of 133 MHz operation
–PCI Bus rate of 33 MHz
–20 Mbytes of Local Memory SRAM
–MIL-STD-1553B Bus interface
–4 bi-directional SpaceWire ports
–Dimension 6U x 220mm (front side)
•Dimension 6U x 160mm (back side)
–Power is to be 15 Watts Average
–+3.3V Nominal Operation
•The EEPROM devices use +5.0V

Backplane Speed of 32Mbytes/sec (@ 33Mhz Bus Rate) ~ 256Mbps meets Raw Data Rate requirement of 56 Mbps

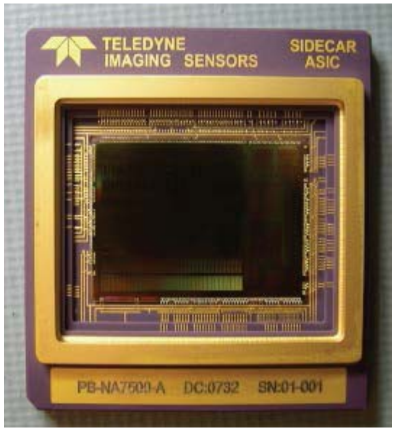
Teledyne SIDECAR ASIC

S System (for)
I Image
D Digitization
E Enhancement
C Control
A And
R Retrieval

ASIC

Manages FPA Operation and Science Data Digitization

- 36 Video Input Channels
- 20 Analog Output Channels
- 32 Digital I/O (Clocks)
- 20 Bias Generators
- 16-Bit Programmable Microprocessor

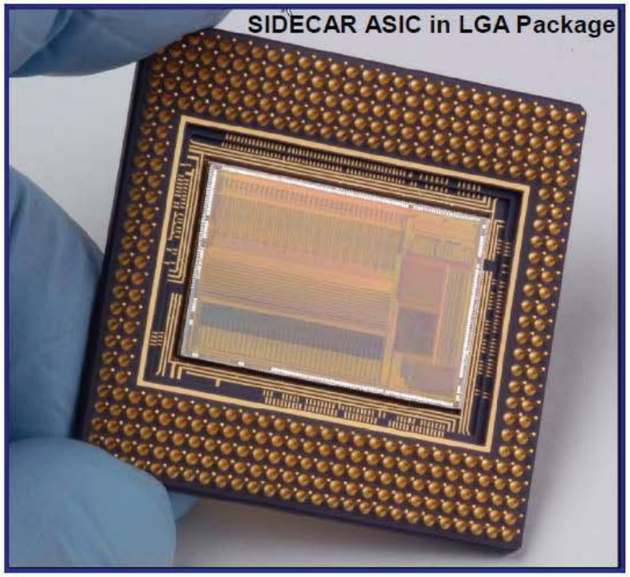


SIDECAR ASIC

The SIDECAR™ ASIC is designed to manage all aspects of imaging array operation and output digitization.

SIDECAR™ ASIC Hardware:

- 36 analog to digital processing channels
  - Accommodates all 32 outputs of a H2RG™ focal plane array, plus reference output, window output, and temperature sensor
  - Preamplifier gain: 0dB – 27dB in 3dB steps
  - 16 bit analog-to-digital converter (ADC): up to 500 kHz sample rate
  - 12 bit ADC: up to 10 MHz sample rate
- Clock generation
  - 32 programmable digital I/O signals
- Bias generation
  - 20 programmable bias voltages/currents
- Digital interface to instrument electronics
  - 24 digital input/output channels for data transfer (LVDS or CMOS)
- 16-bit fully programmable microcontroller
- Low power operation
  - Less than 150 mW at 100 kHz, 32 channel, 16 bit ADC
  - Less than 1 W at 10 MHz, 32 channel, 12 bit ADC
  - Efficient power-down modes
- Requires one power supply, one fixed reference and one master clock for operation



155 MSPS 14-bit ADC

ADC14155QML-SP, TI (National Semiconductor)

- 14-bits, ENOB ~11.3
- Sample Speed ~ 155MHz
- Power consumption ~ 0.967W
- Input Bandwidth ~ 1.1GHz
- Input Range ~ 2V(p-p)

Teledyne HAWAII-1RG
Read Out Integrated Circuit (ROIC)

H HgCdTe
A Astronomy
W Wide
A Area
I Infrared
I Imager

1 1024 x 1024 Pixels
R Reference Pixels
G Guide Mode

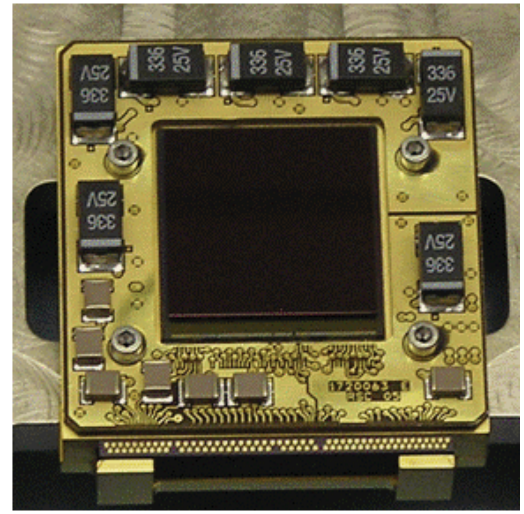
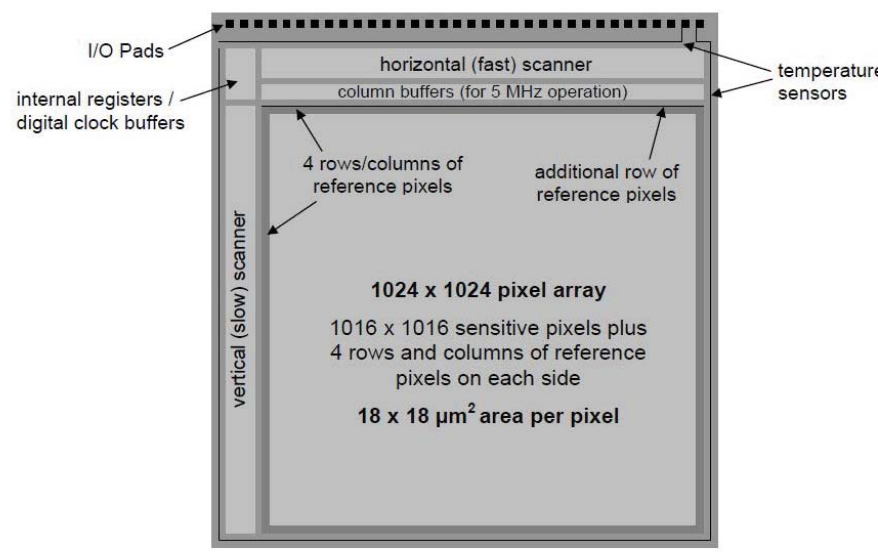


Figure 1.1: Block diagram of the HAWAII-1RG



GEO CAPE Filter Radiometer (FR)

~ Concept Presentations ~

Thermal

Mike Choi

Aug 12, 2014

Summary of Cases

Integrated Design Capability / Instrument Design Laboratory

Baseline	“Descope” Case
MCT HAWAII-4RG Detector	UV/Vis/NIR Silicon CCD Detector
SIDECAR (1)	Digitizers (2)

Operating Mode Thermal Requirements

Component	Temperature (ºC)	Temperature Stability (ºC)
MCT HAWAII-4RG (Baseline)	-88 (185K)	±0.01
UV/Vis/NIR Silicon CCD (Descope)	20 (293K)	±0.1
Optics	20	±3
Optical Bench	20	±3
Optics Enclosure	20	±3

Operating Mode Thermal Requirements

Component	Temperature (°C)	Thermal Stability (°C)
µASC-CHU (2)	-10 to 60	N/A
µASC DPU	-10 to 40	N/A
IMU Sensor	-10 to 50	±3
IMU Electronics Box	-10 to 40	N/A
Digitizer	-10 to 40	±5
Main Electronics Box (MEB)	-10 to 40	N/A
Roll Camera	0 to 45	N/A
Scan Mirror Mechanism	-20 to 20	±3
Fast Steering Mirror Mechanism	-30 to 50	±3
Diffuser Wheel Mechanism	-10 to 60	N/A
Jitter Suppression Mechanism	-50 to 60	N/A
Filter Wheel Mechanism	-20 to 20	N/A
Contamination Cover Mechanism	-40 to 50	N/A

Survival Mode Thermal Requirements

Component	Temperature (°C)
MCT HAWAII-4RG (Baseline)	-238 to 60
UV/Vis/NIR Silicon CCD (Descope)	-40 to 60
Optics	-30 to 60
Optical Bench	-30 to 60
Optics Enclosure	-30 to 60

Survival Mode Thermal Requirements

Component	Temperature (ºC)
µASC-CHU	-55 to 85
µASC DPU	-30 to 60
IMU Sensor	-30 to 60
IMU Electronics Box	-30 to 60
Digitizer	Baseline: -238 to 60; Descope: -40 to 60
Main Electronics Box (MEB)	-30 to 60
Roll Camera	-30 to 60
Scan Mirror Mechanism	-30 to 60
Fast Steering Mirror Mechanism	-30 to 60
Diffuser Wheel Mechanism	-30 to 60
Jitter Suppression Mechanism	-50 to 100
Filter Wheel Mechanism	-30 to 60
Contamination Cover Mechanism	-40 to 70

Operating Mode Power Dissipation

Component	Power Dissipation (W)
MCT HAWAII-4RG (Baseline)	0.01
UV/Vis/NIR Silicon CCD (Descope)	4
Optics	0
Optical Bench	0
Optics Enclosure	0

Operating Mode Power Dissipation

Component	Power Dissipation (W)
µASC-CHU (2)	0.9 each
µASC DPU	3.1
IMU Sensor	1
IMU Electronics Box	23
SIDECAR (Baseline)	2
Digitizer (Descope)	2@16
Main Electronics Box (MEB)	74.9
Roll Camera	23
Scan Mirror Mechanism	0.011
Fast Steering Mirror Mechanism	2.9
Diffuser Wheel Mechanism	2
Jitter Suppression Mechanism	5
Filter Wheel Mechanism	6.5
Contamination Cover Mechanism	0

Differences in Electronics Boxes & Mechanisms Power between Cases

- **Electronics boxes and mechanisms have 145.2 W power dissipation in baseline**
- **Descope case have 30 W more power in digitizer**
  - Total power dissipation is 175.2 W
- **30% uncertainty margin to assure conservatism in worst hot case thermal analysis**

Standby Mode Power Dissipation

	Power Dissipation (W)
Baseline	Detector: 0.01; Electronics Boxes and Mechanisms: 79.7
Descope	Detector: 4; Electronics Boxes and Mechanisms: 77.1

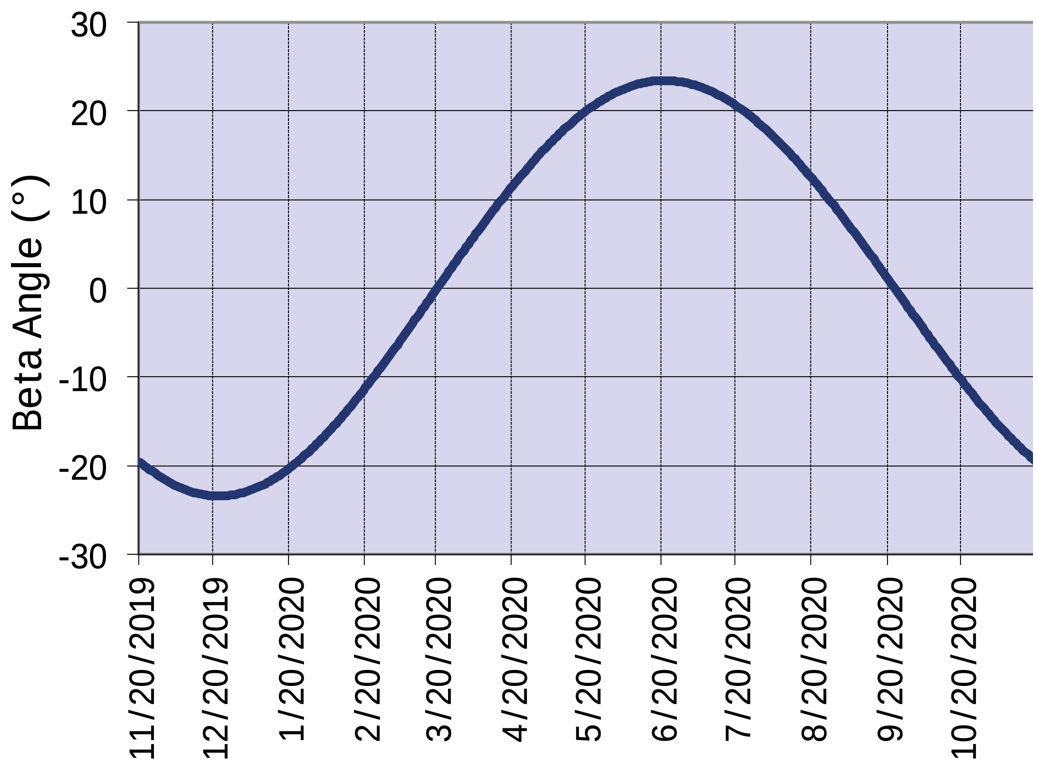
Instrument Thermal Interface with Spacecraft

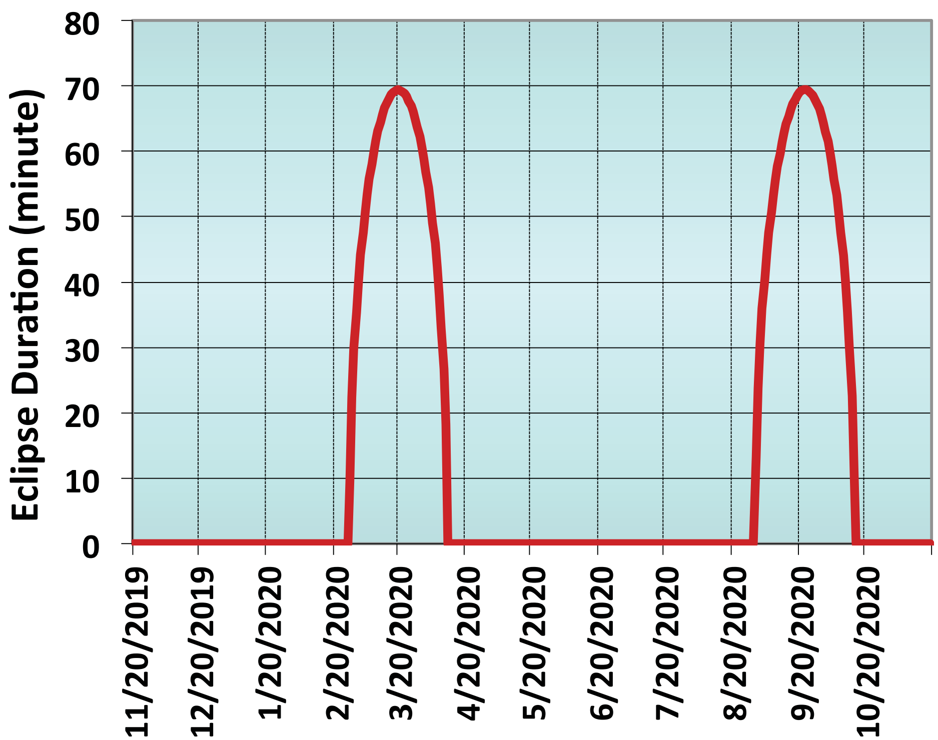
- Instrument is thermally isolated from spacecraft nadir deck
- Spacecraft geometry, dimensions and components viewed by instrument are not known

Orbit Parameters

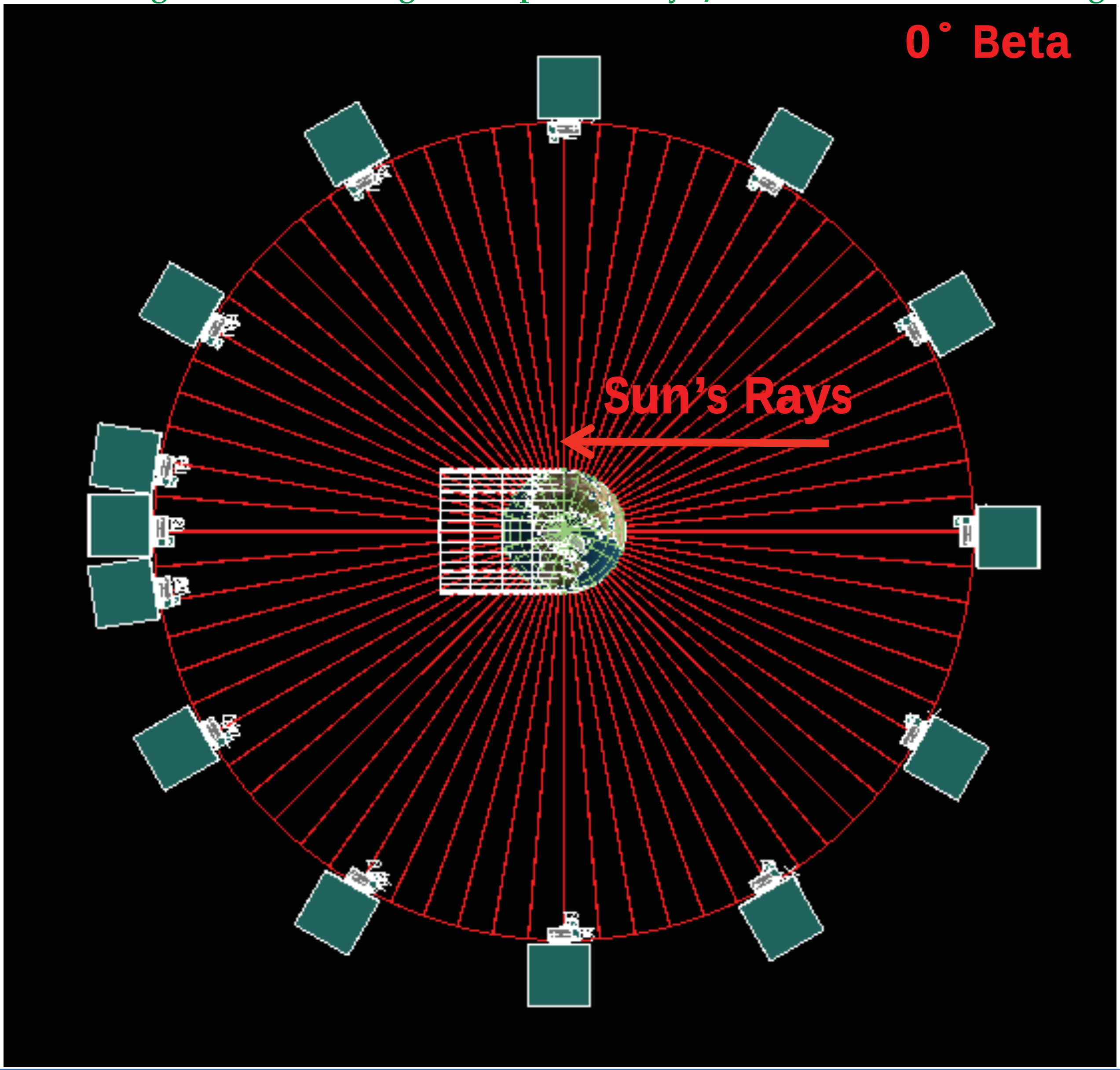
- Geostationary orbit
- 35,786 km altitude
- 0º inclination

Beta Angle and Eclipse Duration



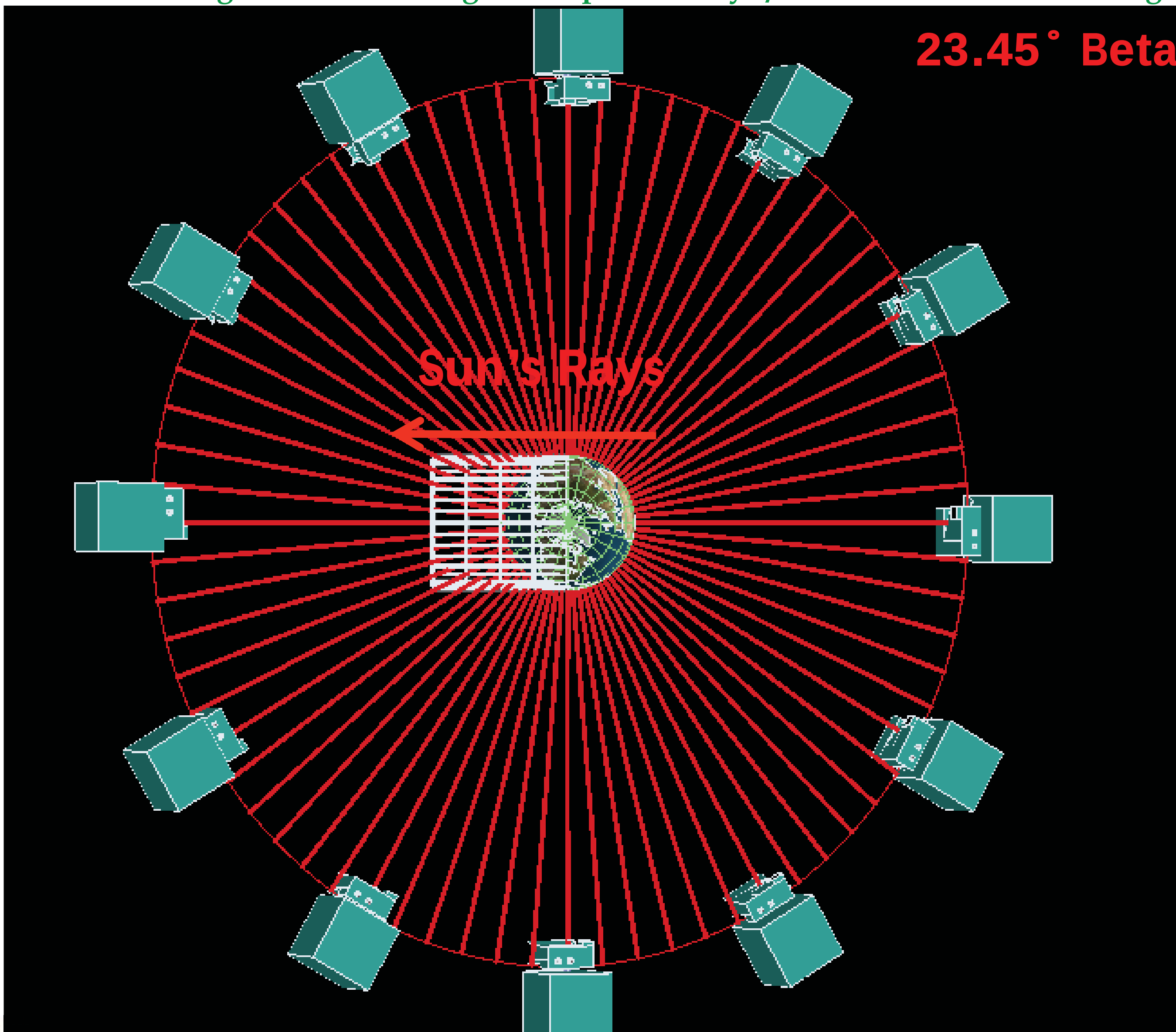


GEO Orbit



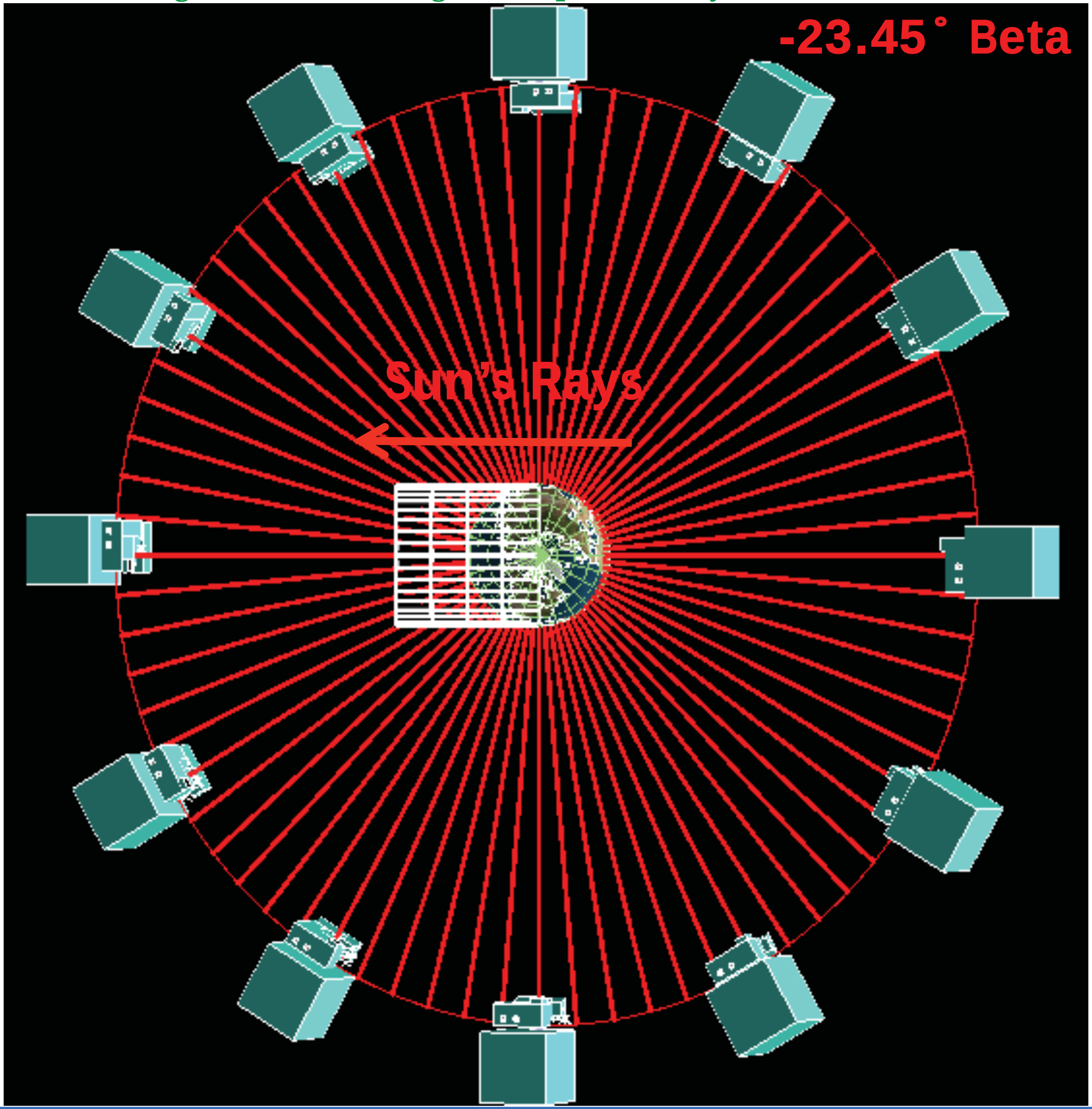
24 Hour Orbit Period

GEO Orbit



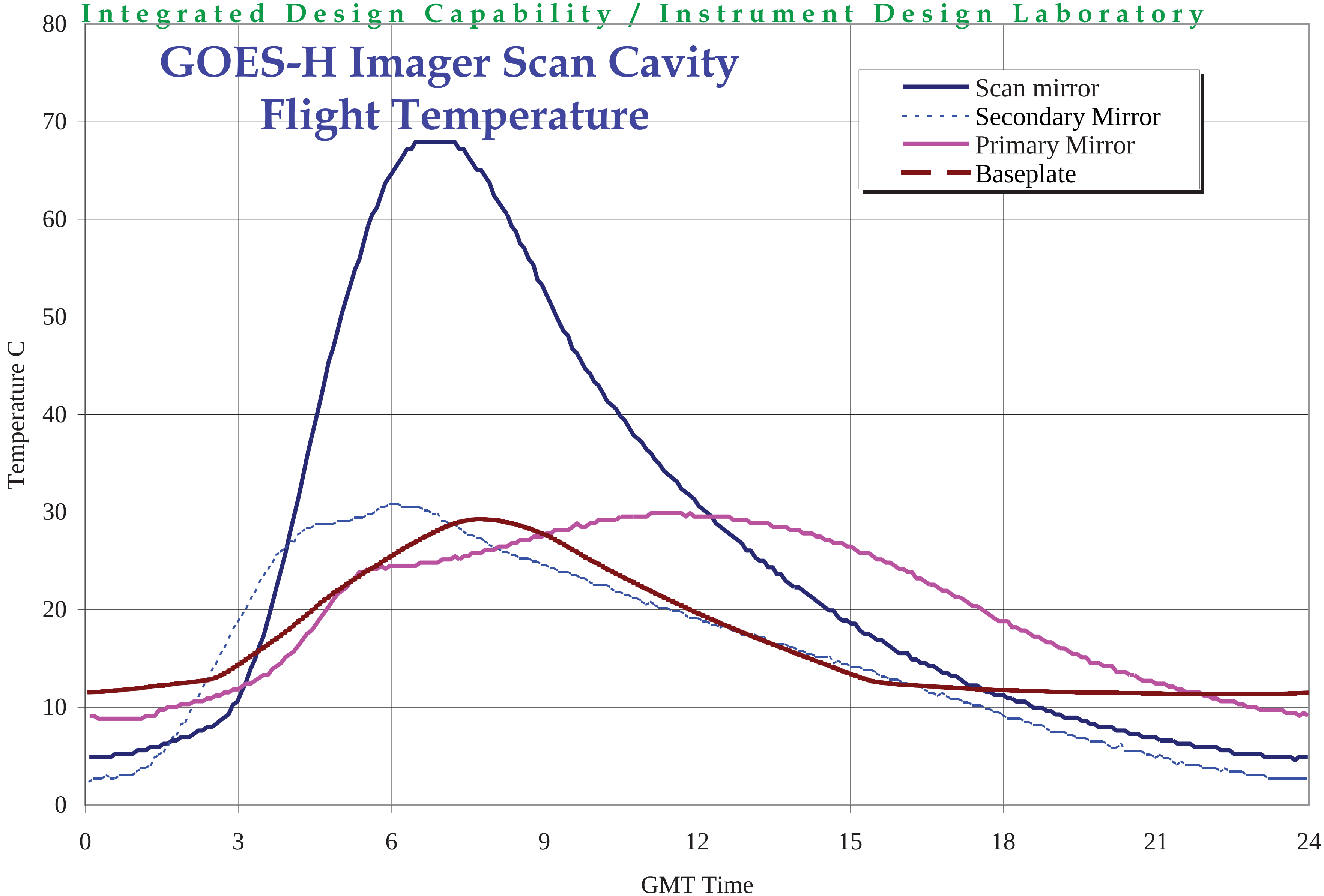
24 Hour Orbit Period

GEO Orbit



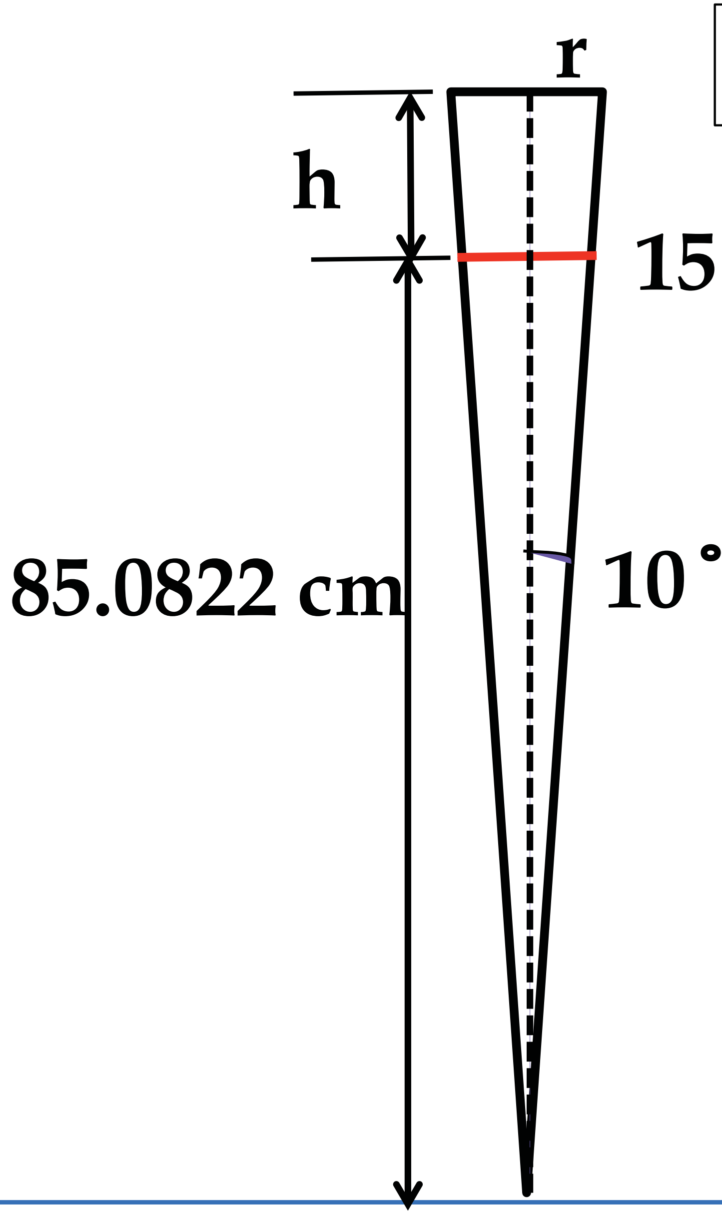
24 Hour Orbit Period

Issue of Solar Flux Entering Scan Aperture



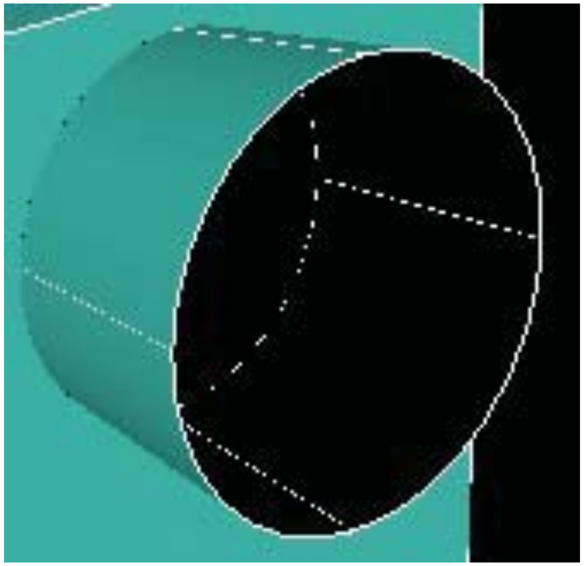
Aperture Baffle Sizing

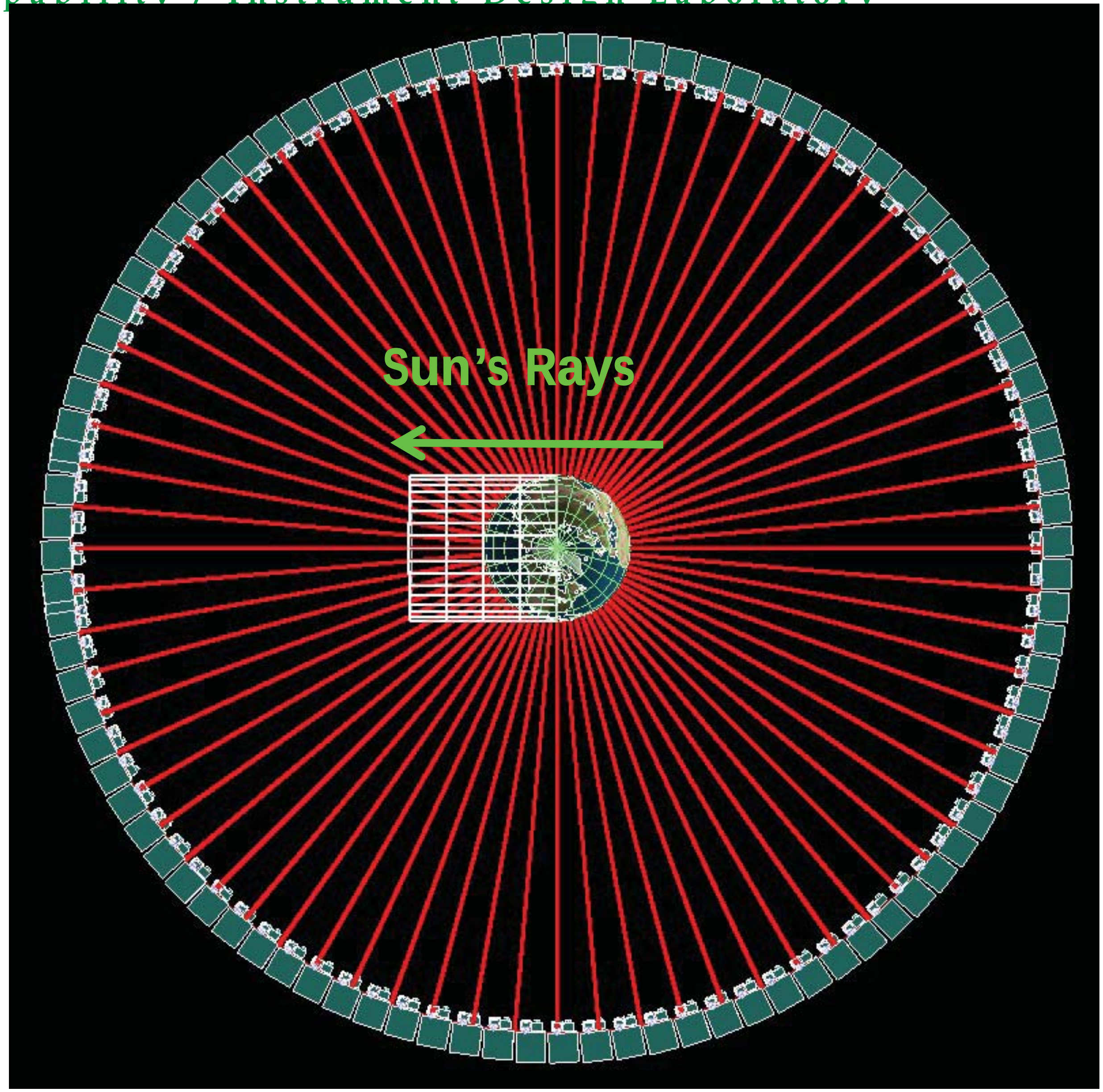
$$r = 0.1763\ (h+85.0822)$$



h (cm)	r (cm)
5	15.881
10	16.763
15	17.644
20	18.526
25	19.407

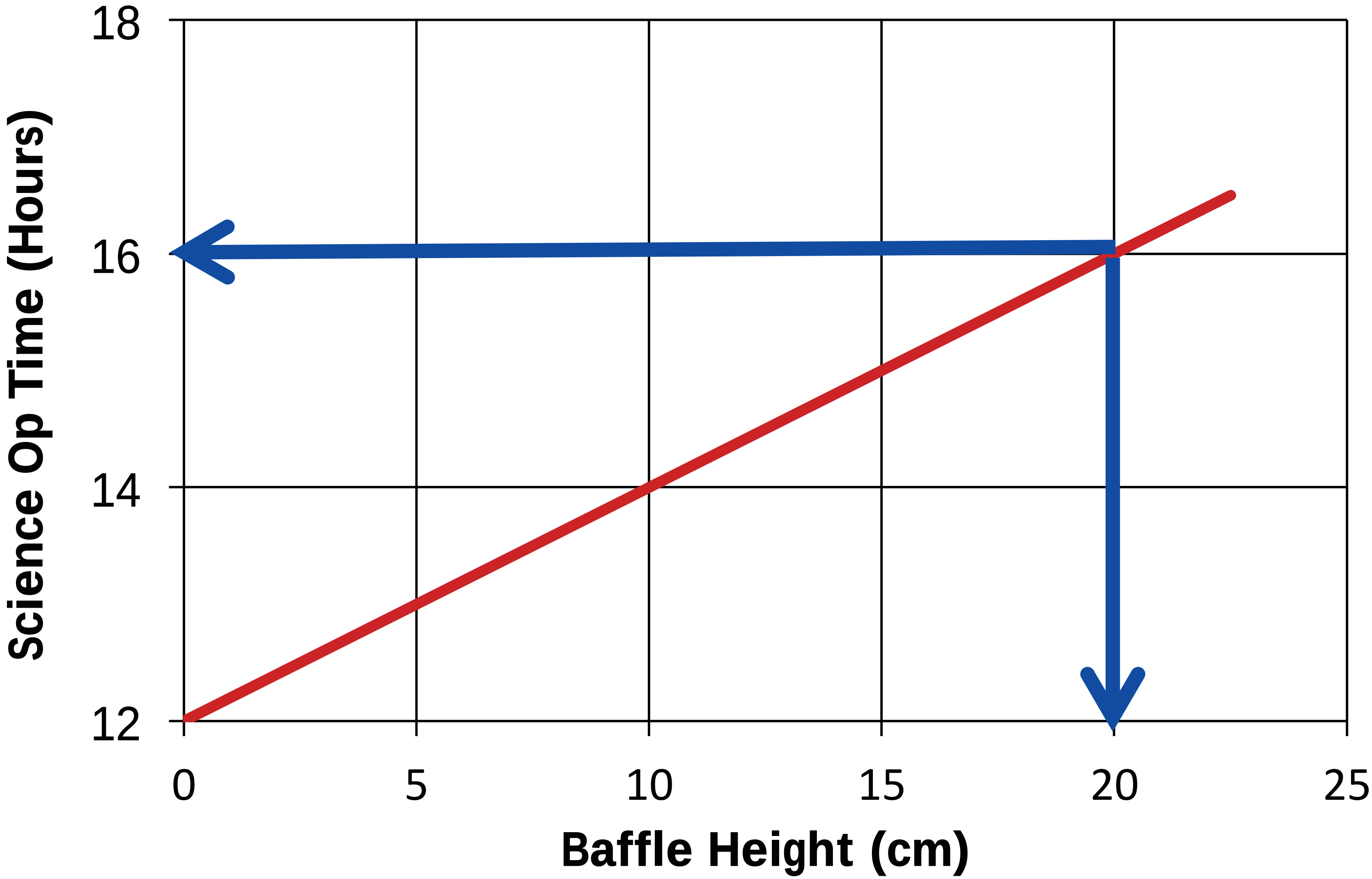
Aperture Baffle to Meet 16 Hours Continuous Science Operation





Solar flux entering scan cavity is tracked in 15 minute intervals (i.e., 96 orbit positions) in thermal model

Aperture Baffle to Meet 16 Hours Continuous Science Operation



Sunlight Scattering

- **If aperture baffle interior is coated with Aeroglaze Z307 black paint (absorptance of 0.96), sunlight incident on it will be diffusely reflected**
- **Materials/coatings with near 1.0 solar absorptance may be considered**

Thermal Coating

- **Radiators have optical solar reflector/indium tin oxide (OSR/ITO) conductive coating**
- **MLI outer cover has conductive silver composite coating**
  - Low absorptance and high emittance to keep temperature cool
  - Low surface resistivity

Detector Thermal Control

- Detectors are cold biased by passive cooling
- Trim heaters maintain detector temperature stable
- Detector thermally isolated from optical bench/ optics enclosure
- Short thermal strap transfers heat from detector to cold finger
- Constant conductance heat pipe (CCHP) transfers heat from cold finger to North or South radiator
- Sun-shade/baffle for radiator
  - Exterior insulated with MLI
- CCHPs are insulated with MLI

Detector Thermal Control

- **Parasitic heat load is major MCT HAWAII-4RG (baseline) detector heat load since detector and radiator are about 110K colder than optics enclosure and optical bench, and radiator sunshade also contributes heat load**
  - 1 W plus 50% uncertainty margin
- **Survival heaters**
  - Bimetallic thermostats for heater control
- **MCT HAWAII-4RG detector has decontamination heater**
  - Commanded on/off
  - Bimetallic thermostats for over-temperature protection

Electronics Boxes Thermal Control

- **Electronics boxes thermally isolated from optical bench/optics enclosure**
- **Constant conductance heat pipe (CCHP) transfers heat from electronics boxes to North or South radiator**
- **Sun-shade/baffle for radiator**
  - **Exterior insulated with MLI**
- **Electronics boxes and CCHPs are insulated with MLI**
- **Survival heaters**
  - Bimetallic thermostats for heater control

Mechanism Thermal Control

- **Scan Mirror, Filter Wheel, Fast Steering Mirror, Jitter Suppression and Diffuser Wheel mechanisms are thermally coupled to electronics boxes CCHP**
- **Survival heaters for all mechanisms, including contamination cover mechanism**
  - Bimetallic thermostats for heater control

Optical Bench and Optics Enclosure Thermal Control

- **Optical Bench, Optics Enclosure and flexures have active heater control and MLI**
  - Bimetallic thermostats for heater control
- **Survival heaters**
  - Bimetallic thermostats for heater control

Optics and Optical Bench Thermal

- Instrument thermally isolated from spacecraft
- Flexures and exterior of optics enclosure and optical bench insulated with MLI thermal blankets
- Optical bench thermally isolated from spacecraft
- Thermal coating for interior of optics enclosure and optical bench is Aeroglaze Z307 black paint
- Kapton film heaters attached to selected locations of optics enclosure exterior and optical bench to maintain optics at 20ºC in operating mode
  - Operating mode heater circuits controlled to 20ºC±3ºC by mechanical thermostats
- Other heater circuits
  - Survival heaters

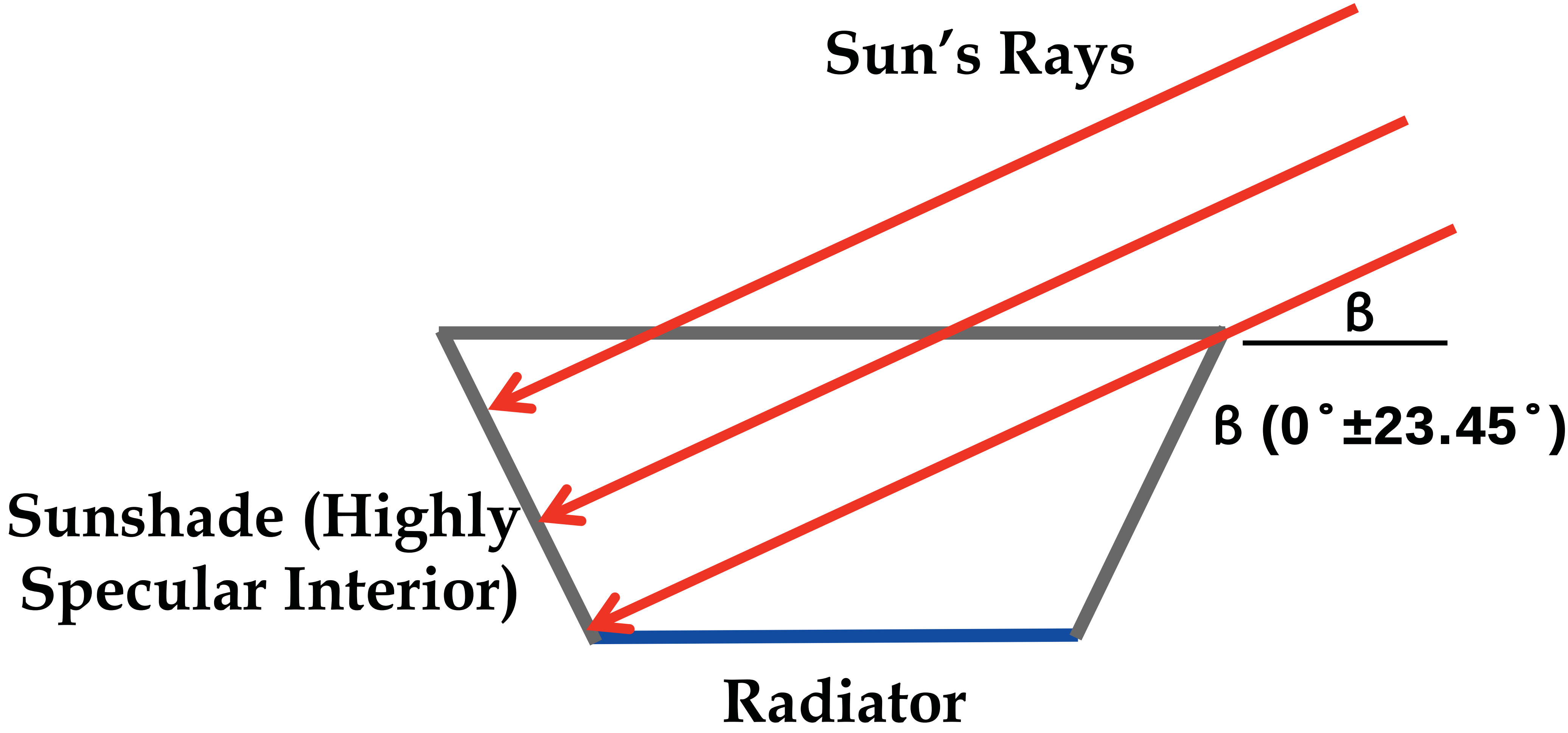
Standby Mode Power Management

- **Detectors, mirror mechanisms and electronics boxes, including digitizers, are in Standby Mode (6.5 hours) to primarily increase reliability**
- **Makeup heater power is required for detectors, mechanisms and electronics boxes**
  - Detector temperature needs to be maintained same as operating mode
  - Temperature of electronics boxes maintained at 20˚C±3˚C

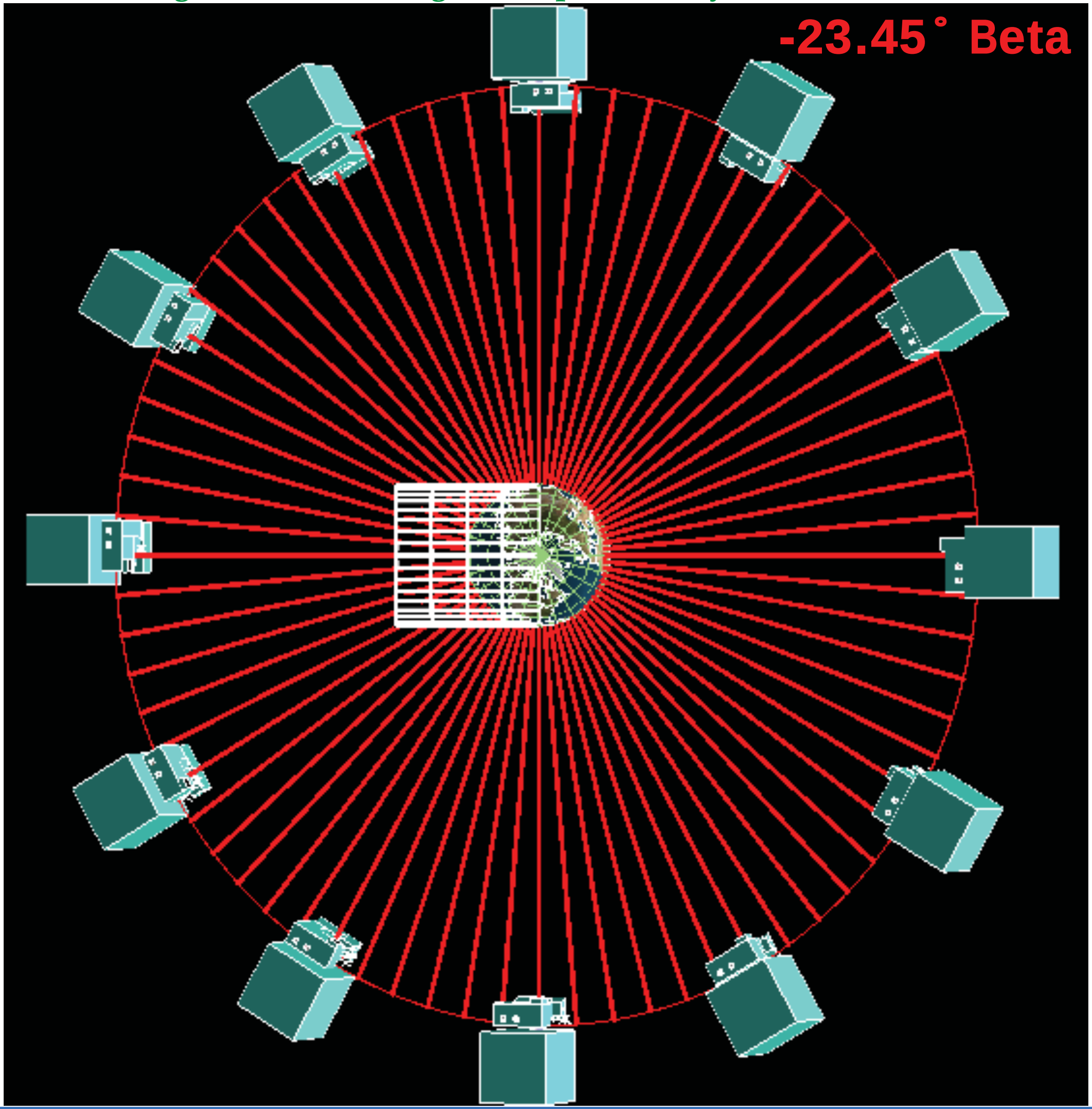
Radiator and Heater Power Sizing

- **Radiators are sized in worst hot operating case**
- **Operating mode heater power is sized in worst cold operating case**
- **GSFC Gold Rules call for a maximum of 70% heater duty cycle for an active heater control thermal design**
  - In sizing heater electrical resistance (R), orbital average heater power shall be no more than 70% of peak heater power (V**2/R)
    - Valid for both bang-bang and proportional/integral/derivative (PID) controllers

Radiator Sunshade

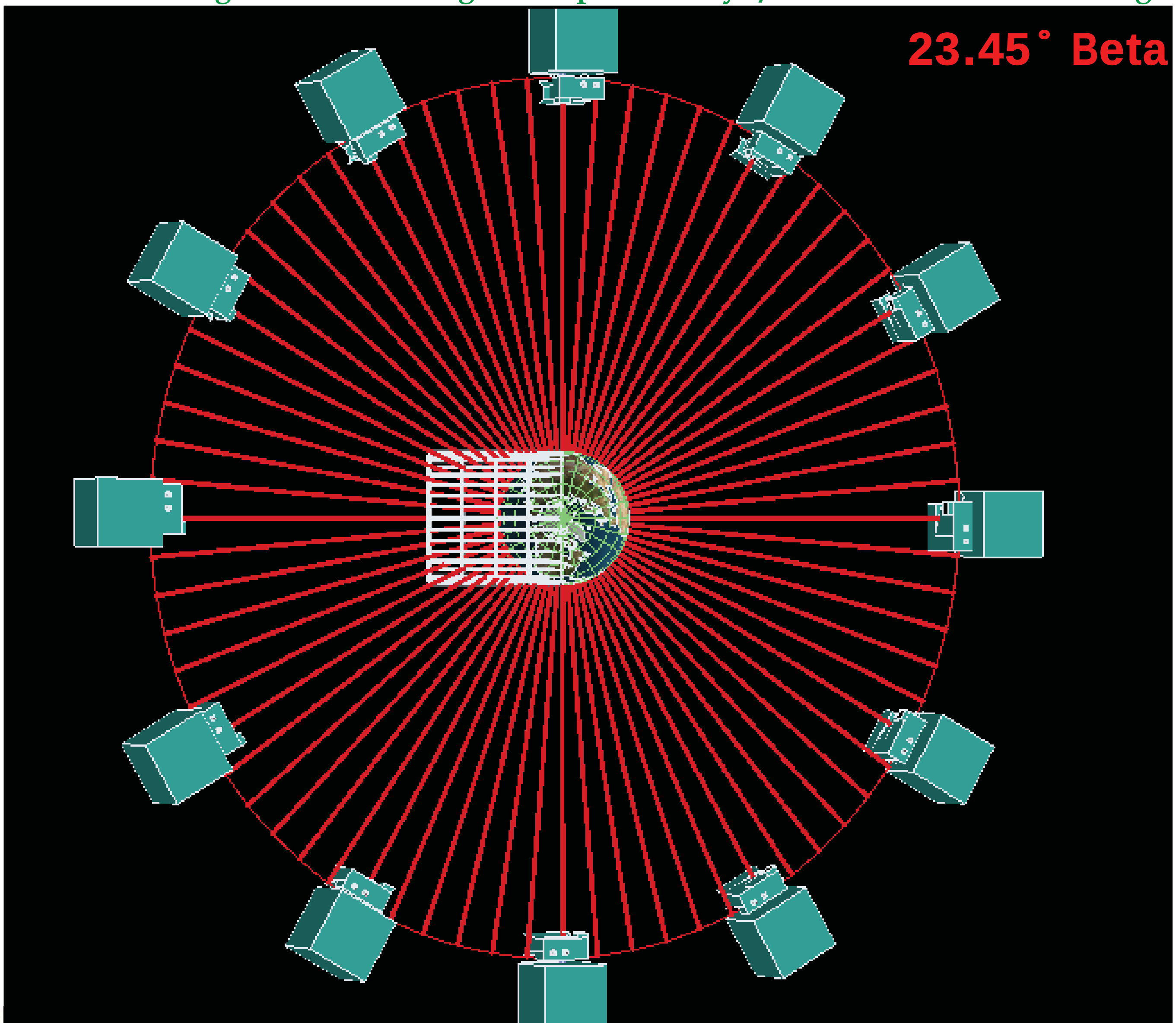


Orbit Thermal Model



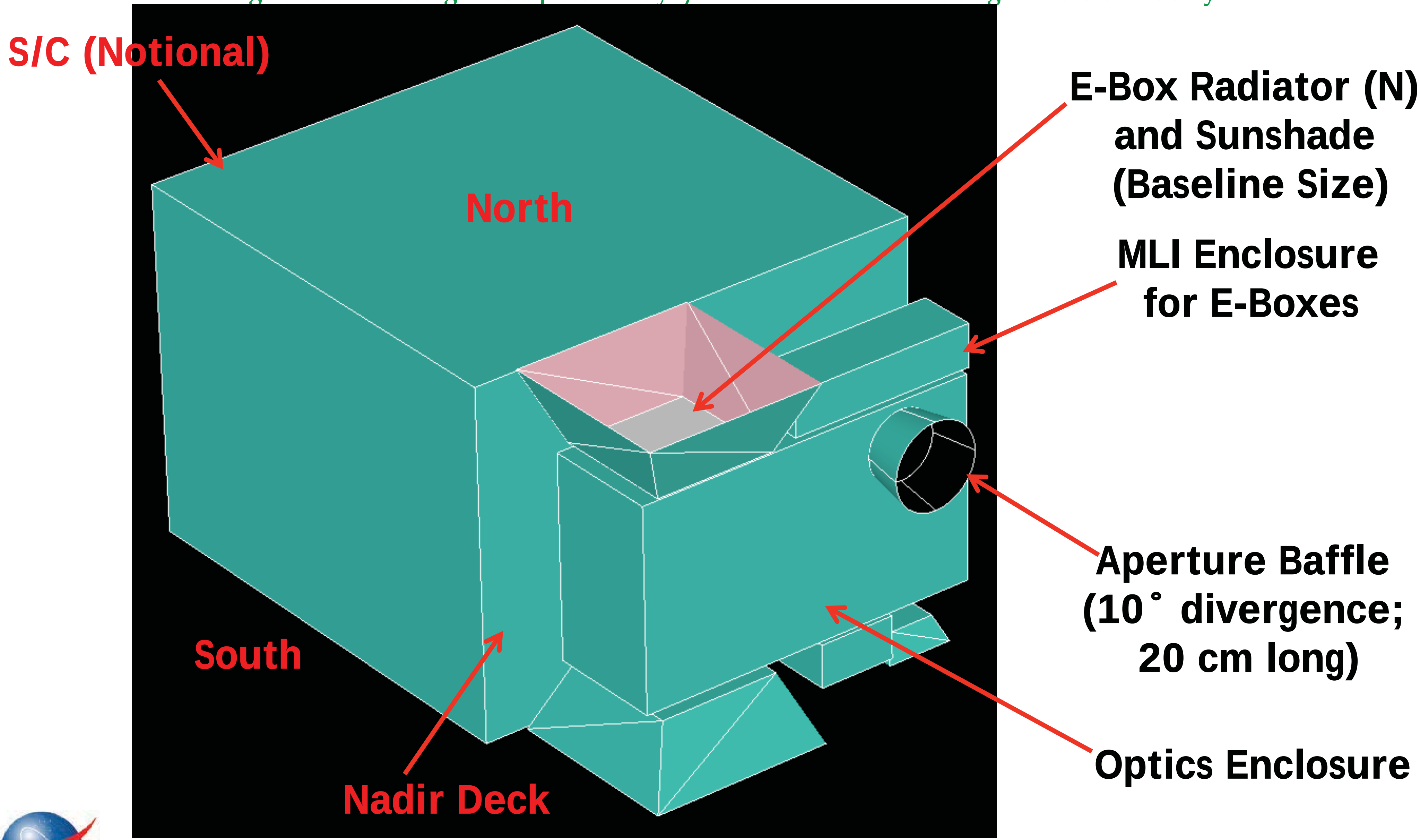
Worst Hot Case for Electronics Boxes South Radiator and Detector Radiator

Orbit Thermal Model

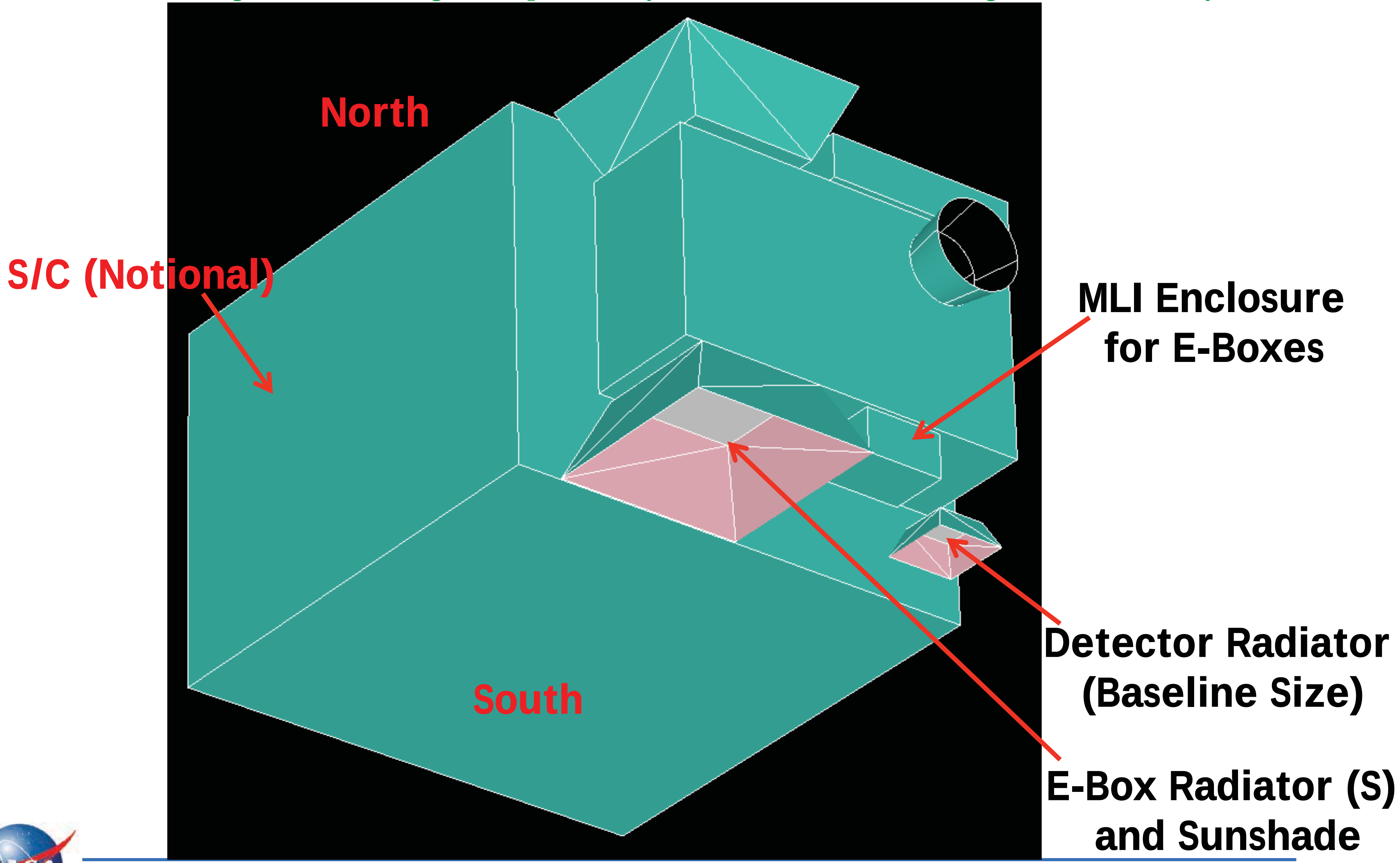


Worst Hot Case for Electronics Boxes North Radiator

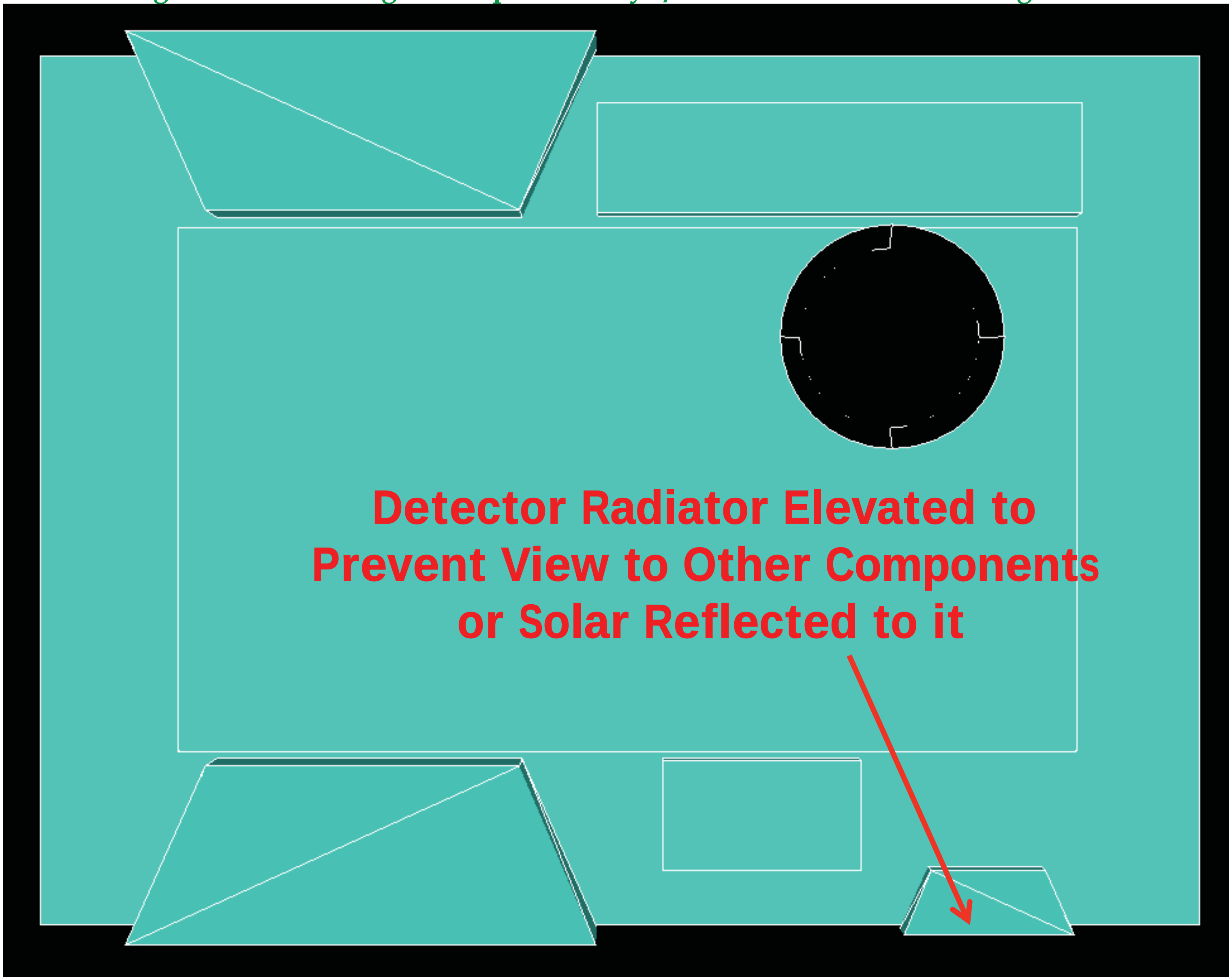
Thermal Model



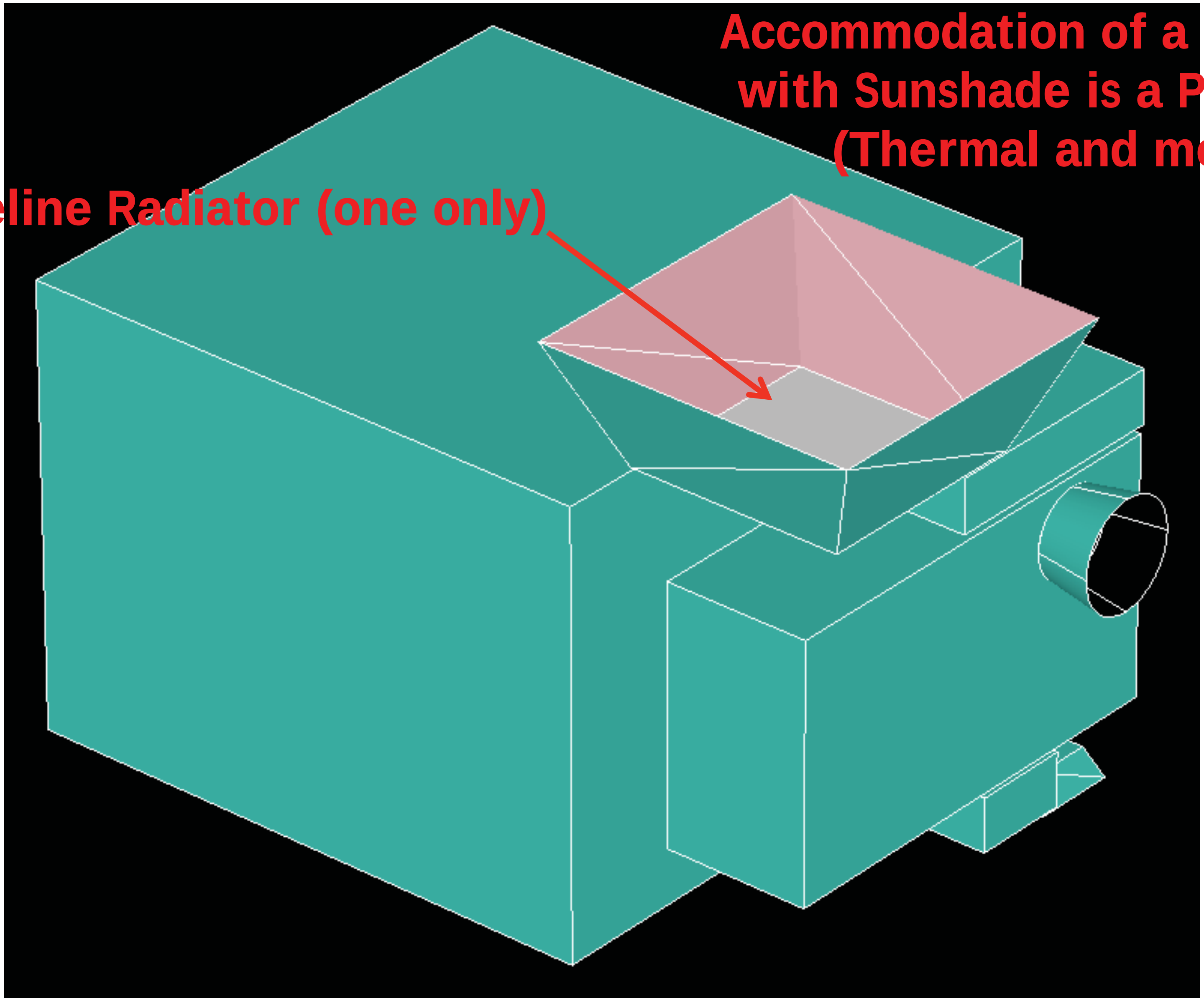
Thermal Model



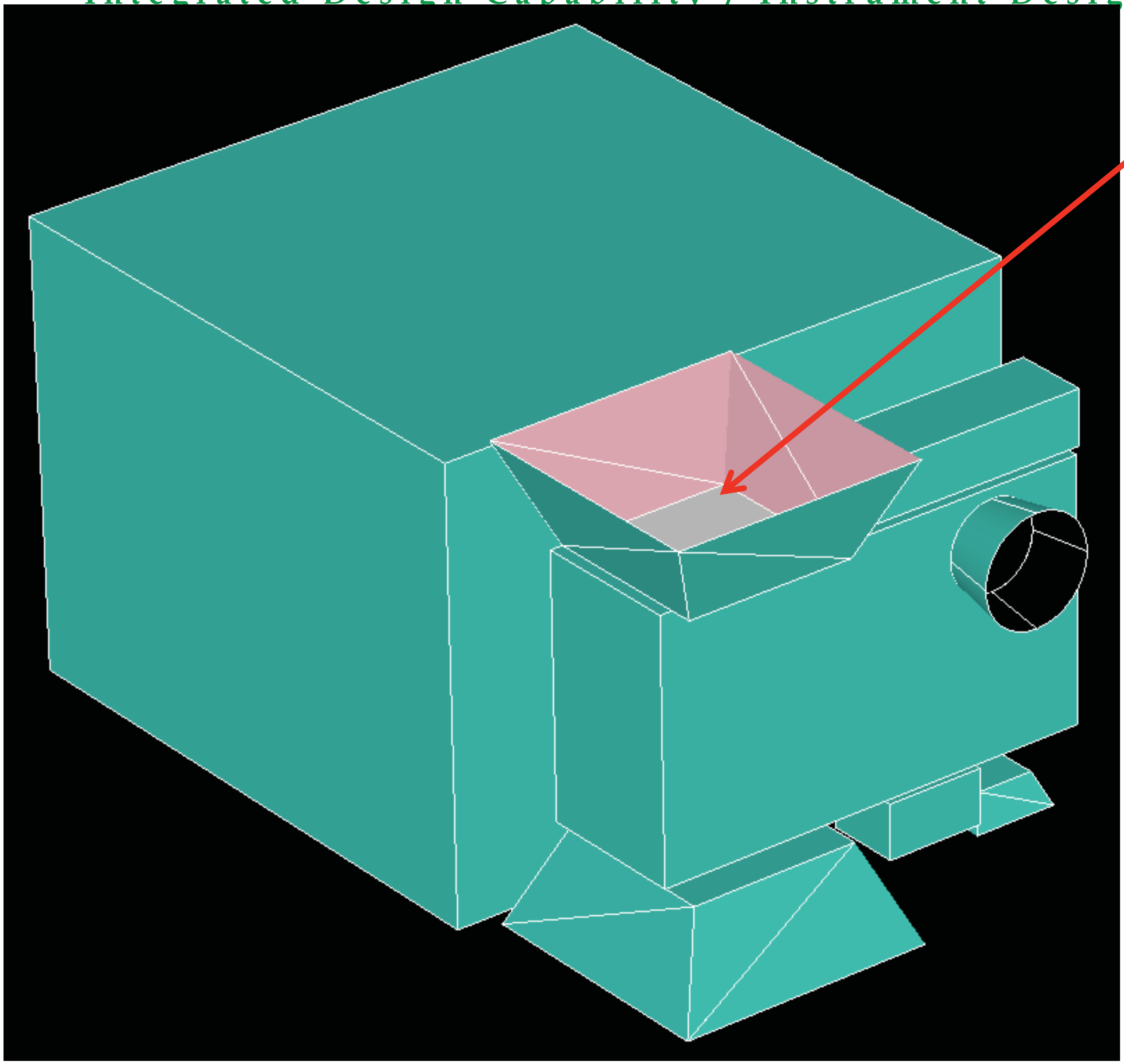
Thermal Model



Issue of One Radiator (N or S) for Electronics Boxes and Mechanisms

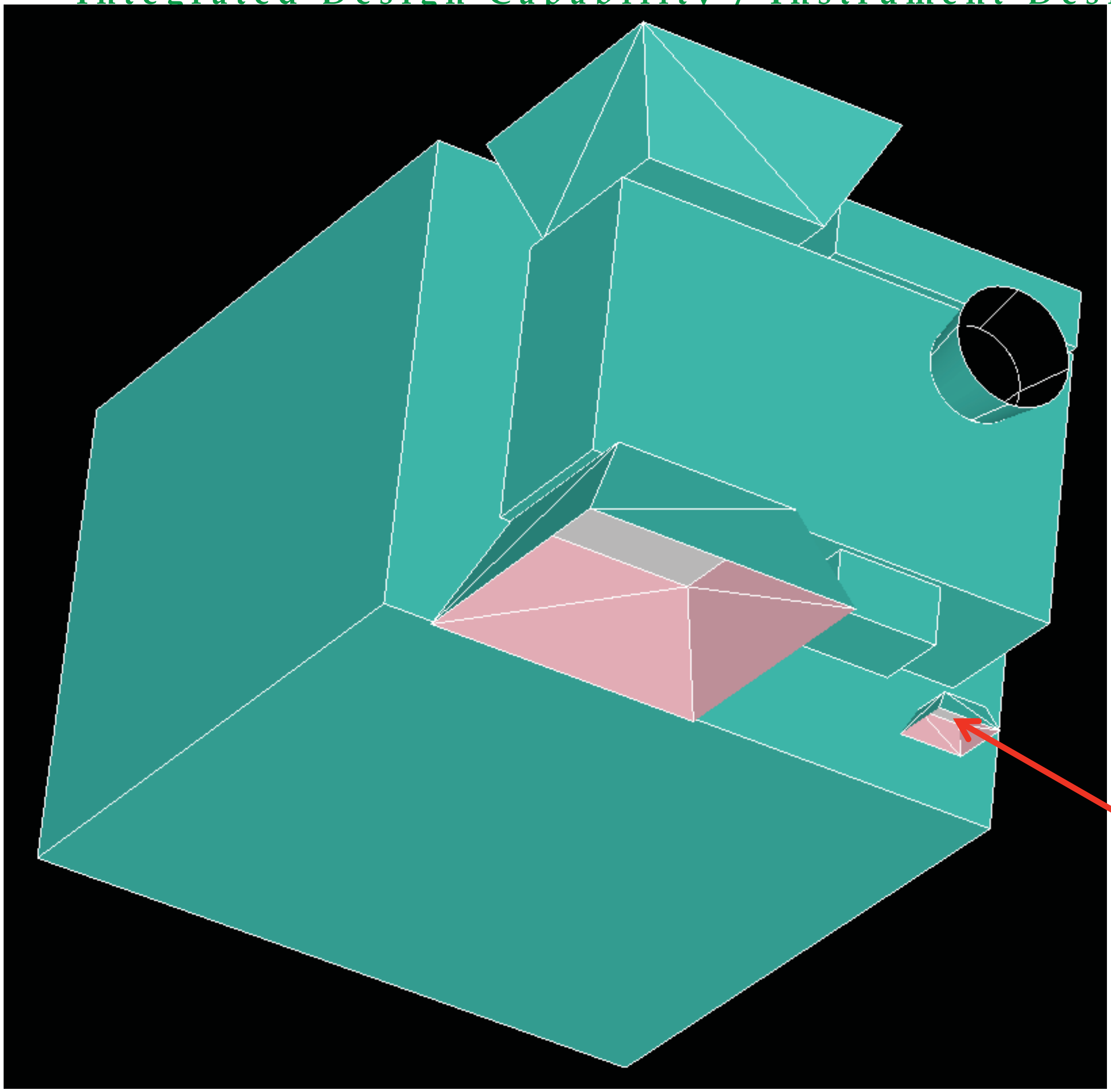


Thermal Model



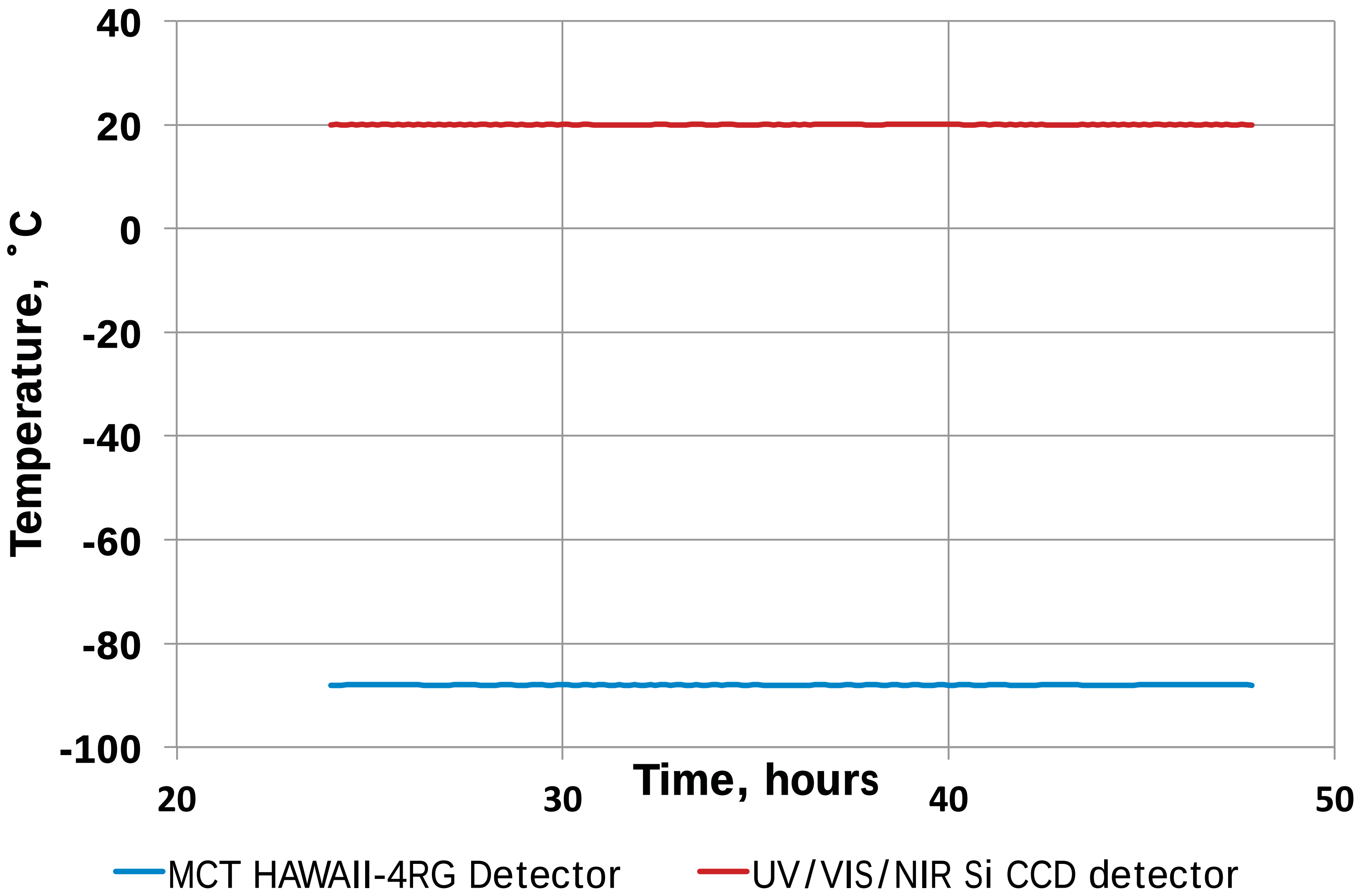
E-Box Radiator (N) and Sunshade (Descope Case Size: About 20% Larger)

Thermal Model

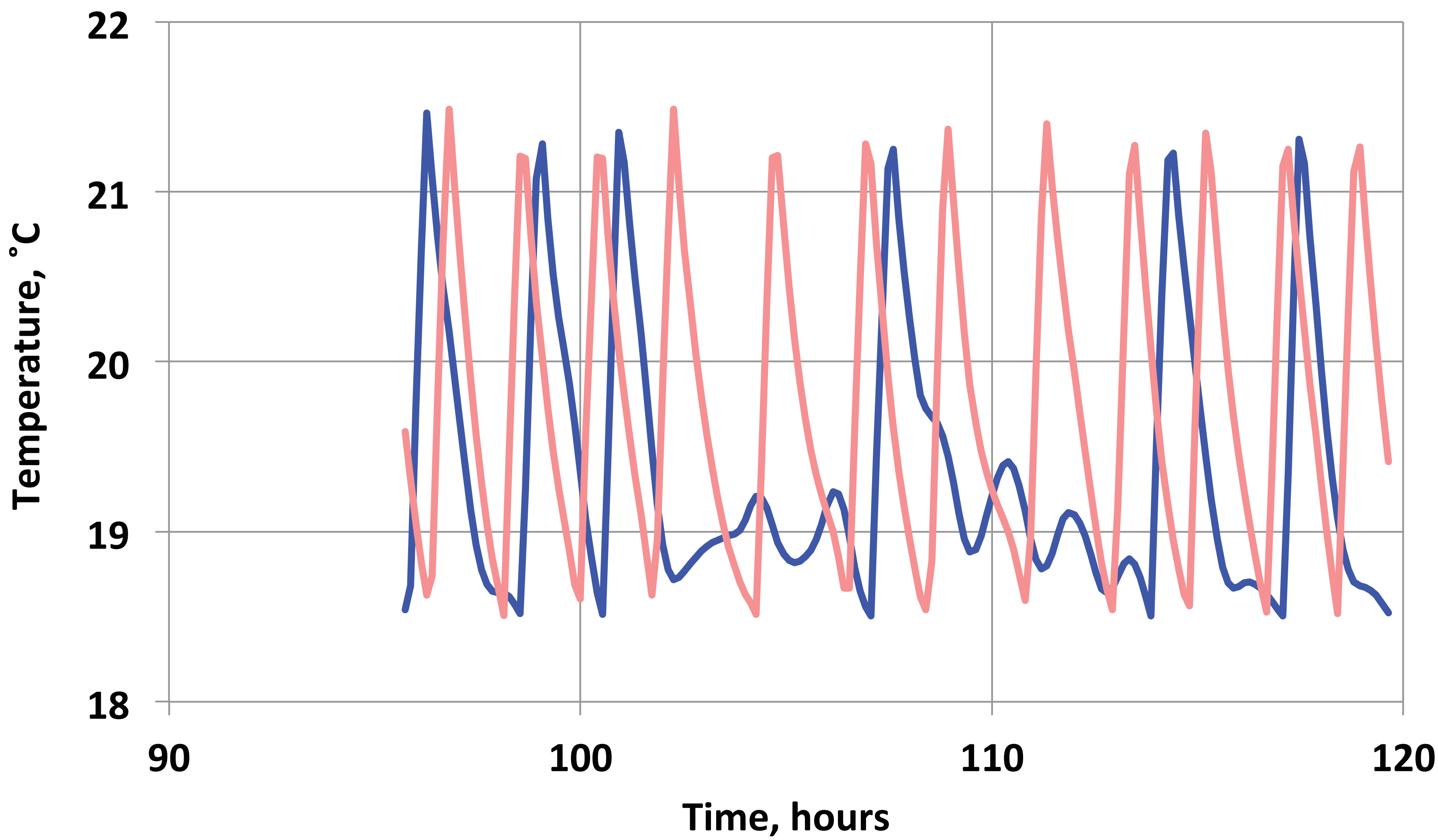


Detector Radiator and Sunshade (Descope Case Size; About Half of Baseline Size)

Detector Worst Cold Case Temperature Predictions (Heater Enabled)



Optics/Optical Bench Worst Cold Case Temperature Predictions (Heater Enabled)



Baseline Radiator Area Summary

Integrated Design Capability / Instrument Design Laboratory

	Radiator Area (m^2)
MCT HAWAII-4RG Detector	0.037
Electronics Boxes and Mechanisms	North: 0.275 South: 0.275

Descope Case Radiator Area Summary

	Radiator Area (m^2)
UV/Vis/NIR Si CCD Detector	0.019
Electronics Boxes and Mechanisms	North: 0.332 South: 0.332

Baseline Operating Mode Heater Circuits

	Control	Primary Circuits	Redundant Circuits
Optical Bench/Optics Enclosure	Mechanical Thermostats	12	12
MCT HAWAII-4RG Detector	Electronics Controller	1	1
Electronics Boxes and Mirror Mechanisms (Standby Mode)	Mechanical Thermostats	13	13
Total		26	26

Descope Case Operating Mode Heater Circuits

	Control	Primary Circuits	Redundant Circuits
Optical Bench/Optics Enclosure	Mechanical Thermostats	12	12
UV/Vis/NIR Si CCD Detector	Electronics Controller	1	1
Electronics Boxes and Mirror Mechanisms (Standby Mode)	Mechanical Thermostats	13	13
Total		26	26

Survival Heater Circuits (Mechanical Thermostat Control)

	Primary Circuits	Redundant Circuits
Optical Bench/Optics Enclosure	6	6
Detector (Baseline or Descope)	1	1
MEB	1	1
IMU Electronics	1	1
IMU Sensor	1	1
Digitizer	1*	1*
ASC/DPU	1	1
ASC/CHU	2	2
Roll Camera	1	1
Scan Mirror Mechanism	1	1
Fast Steering Mechanism	1	1
Diffuser Wheel Mechanism	1	1
Jitter Suppression Mechanism	1	1
Filter Wheel Mechanism	1	1
Contamination Cover Mechanism	1	1
Total	21**	21**

For Descope Case:
*2 instead of 1
**22 instead of 21

Baseline Operating Mode Heater Power

	Average Heater Power (W)
Optical Bench/Optics Enclosure	70
MCT HAWAII-4RG Detector	1.5
Total	71.5

Baseline Standby Mode Heater Power

	Average Heater Power (W)
Optical Bench/Optics Enclosure	70
MCT HAWAII-4RG Detector	1.5
Electronics Boxes and Mirror Mechanisms	98
Total	170

Descope Case Operating Mode Heater Power

	Average Heater Power (W)
Optical Bench/Optics Enclosure	70
UV/Vis/NIR Si CCD Detector	2
Total	72

Descope Case Standby Mode Heater Power

	Average Heater Power (W)
Optical Bench/Optics Enclosure	70
MCT HAWAII-4RG Detector	2
Electronics Boxes and Mirror Mechanisms	136
Total	208

Baseline Cold Survival Heater Power

	Average Heater Power (W)
Optics (Heaters on Optical Bench/Optics Enclosure)	40
MCT HAWAII-4RG Detector	<<1
Electronics Boxes and Mechanisms	80
Total	120

Descope Case Cold Survival Heater Power

	Average Heater Power (W)
Optics (Heaters on Optical Bench/Optics Enclosure)	40
UV/Vis/NIR Si CCD Detector	2
Electronics Boxes and Mechanisms	98
Total	140

Baseline Mass Estimates and TRL

Integrated Design Capability / Instrument Design Laboratory

Instrument Components	Mass Each (kg)	Qty	Mass Total (kg)	TRL
MCT HAWAII-4RG Detector Radiator (0.037 m2; 0.254 cm aluminum)	0.2536	1	0.2536	7
Electronics Boxes and Mechanisms Radiator (0.275 m2; 0.254 cm aluminum)	1.8906	2	3.7812	7
MCT HAWAII-4RG Detector Radiator OSR/ITO and Adhesive (0.037 m2)	0.0475	1	0.0475	9
Electronics Boxes and Mechanisms Radiator OSR/ITO and Adhesive (0.275 m2)	0.3549	2	0.7098	9
MCT HAWAII-4RG Detector Radiator Sun-Shade (0.069 m2; aluminum)	0.2878	1	0.2878	7
Electronics Boxes and Mechanisms Radiator Sun-Shade Support Structure (0.851 m2; hogged out 0.254 cm aluminum)	0.8192	2	1.6384	7
Heat Pipe (CCHP) for MCT HAWAII-4RG Detector (1 m long; 1.27 cm diam.; aluminum; ethane)	0.2	2	0.4	7
Heat Pipe (CCHP) for Electronics Boxes and Mechanisms (3 m long; 1.27 cm diam.; aluminum; ammonia)	0.6	2	1.2	7
Spreader CCHP for Electronics Boxes and Mechanisms Radiator (0.5 m long; 1.27 cm diam.; aluminum; ammonia)	0.1	8	0.8	7
K1100 Heat Strap from MCT HAWAII-4RG Detector to Cold Finger (7.62 cm long)	0.132	1	0.132	7
Aeroglaze Z307 black paint for Optics Enclosure and Optical Bench (5 m2)	0.45	1	0.45	9
Aeroglaze Z307 black paint for aperture baffle interior (0.582 m2)	0.0194	1	0.0194	9
MLI (15-layers) on Backside ofMCT HAWAII-4RG detector Radiator (0.037 m2)	0.0222	1	0.0222	9
MLI (15-layers) for MCT HAWAII-4RG ethane heat pipes (0.12 m2)	0.072	1	0.072	9
MLI (15-layers) for Electronics Boxes and Mechanisms Heat Pipes (0.36 m2)	0.216	1	0.216	9
MLI (15-layers) for Optics Enclosure and Optical Bench (5 m2)	3	1	3	9
MLI (15-layers) for aperture baffle (0.215 m2)	0.129	1	0.129	9
MLI (15-layers) for aperture deployable contamination cover (0.126 m2)	0.0756	1	0.0756	9
MLI (15-layers) on Backside of Electronics Boxes and Mechanisms Radiator (0.275 m2)	0.165	2	0.33	9
MLI (15-layers) on MCT HAWAII-4RG Detector Radiator Sun-Shade (0.069 m2)	0.0407	1	0.0407	9
MLI (15-layers) on Electronics Boxes and Mechanisms Radiator Sun-Shade (0.851 m2)	0.478	2	0.956	9
MLI (15-layers) HAWAII-4RG ethane heat pipes (0.12 m2)	0.072	1	0.072	9

Baseline Mass Estimates and TRL

Instrument Components	Mass Each (kg)	Qty	Mass Total (kg)	TRL
MLI (15-layers) for Diffuser Wheel Enclosure (0.25 m2)	0.15	1	0.15	9
MLI (15-layers) for MCT HAWAII-4RG Detector Housing Exterior (0.08 m2)	0.048	2	0.096	9
MLI (15-layers) for MEB (0.247 m2)	0.148	1	0.148	9
MLI (15-layers) for MCT HAWAII-4RG Digitizers (0.1088 m2)	0.0653	1	0.0653	9
MLI (15-layers) for IMU Sensor (0.461 m2)	0.2768	1	0.2768	9
MLI (15-layers) for IMU Electronics Box (0.218 m2)	0.131	1	0.131	9
MLI (15-layers) for ASC DPU (0.107 m2)	0.064	1	0.064	9
MLI (15-layers) for ASC CHU and Baffles (0.032 m2)	0.019	2	0.038	9
MLI (15-layers) for roll camera (0.658 m2)	0.3948	1	0.3948	9
Thermistors/Platinum RTDs for Telemetry	0.001	30	0.03	9
Thermistors/Platinum RTDs for Heater Control (Redundancy included)	0.001	2	0.002	9
Thermostats for Op Heaters -- Honeywell 3100 Series (Redundancy included)	0.006	96	0.576	9
Thermostats for Survival Heaters -- Honeywell 3100 Series (Redundancy included)	0.006	96	0.576	9
Op Heaters -- Kapton Film 5.5 cm x 6.4 cm (Redundancy included)	0.002	8	0.016	9
Op Heaters -- Kapton Film 20 cm x 20 cm (Redundancy included)	0.0229	48	1.0992	9
Survival Heaters -- Kapton Film 5.5 cm x 6.4 cm (Redundancy included)	0.002	96	0.192	9
Buttons, Velcro and Tape for MLI	0.4	1	0.4	9
Adhesive (STYCAST, Nusil) and Aluminum Tape for Heaters, Thermostats and Thermistors/Platinum RTDs	0.3	1	0.3	9
Total			19.1883	

Descope Case Mass Estimates and TRL

Instrument Components	Mass Each (kg)	Qty	Mass Total (kg)	TRL
UV/Vis/NIR Si CCD Detector Radiator (0.019 m2; 0.254 cm aluminum)	0.1302	1	0.1302	7
Electronics Boxes and Mechanisms Radiator (0.332 m2; 0.254 cm aluminum)	2.2825	2	4.565	7
UV/Vis/NIR Si CCD Detector Radiator OSR/ITO and Adhesive (0.019 m2)	0.0244	1	0.0244	9
Electronics Boxes and Mechanisms Radiator OSR/ITO and Adhesive (0.332 m2)	0.4285	2	0.857	9
UV/Vis/NIR Si CCD Detector Radiator Sun-Shade (0.069 m2; aluminum)	0.1478	1	0.1478	7
Electronics Boxes and Mechanisms Radiator Sun-Shade Support Structure (1.027 m2; hogged out 0.254 cm aluminum)	0.989	2	1.978	7
Heat Pipe (CCHP) for UV/Vis/NIR Si CCD Detector (1 m long; 1.27 cm diam.; aluminum; ammonia)	0.2	2	0.4	7
Heat Pipe (CCHP) for Electronics Boxes and Mechanisms (3 m long; 1.27 cm diam.; aluminum; ammonia)	0.6	2	1.2	7
Spreader CCHP for Electronics Boxes and Mechanisms Radiator (0.5 m long; 1.27 cm diam.; aluminum; ammonia)	0.1	8	0.8	7
K1100 Heat Strap from UV/Vis/NIR Si CCD Detector to Cold Finger (7.62 cm long)	0.132	2	0.264	7
Aeroglaze Z307 black paint for Optics Enclosure and Optical Bench (5 m2)	0.45	1	0.45	9
Aeroglaze Z307 black paint for aperture baffle interior (0.582 m2)	0.0194	1	0.0194	9
MLI (15-layers) on Backside of CCD detector Radiator (0.019 m2)	0.0114	1	0.0114	9
MLI (15-layers) for CCD ammonia heat pipes (0.12 m2)	0.072	1	0.072	9
MLI (15-layers) for Electronics Boxes and Mechanisms Heat Pipes (0.36 m2)	0.216	1	0.216	9
MLI (15-layers) for Optics Enclosure and Optical Bench (5 m2)	3	1	3	9
MLI (15-layers) for aperture baffle (0.215 m2)	0.129	1	0.129	9
MLI (15-layers) for aperture deployable contamination cover (0.126 m2)	0.0756	1	0.0756	9
MLI (15-layers) on Backside of Electronics Boxes and Mechanisms Radiator (0.332 m2)	0.1992	2	0.3984	9
MLI (15-layers) on UV/Vis/NIR Si CCD Detector Radiator Sun-Shade (0.069 m2)	0.0209	1	0.0209	9
MLI (15-layers) on Electronics Boxes and Mechanisms Radiator Sun-Shade (0.851 m2)	0.577	2	1.154	9

Descope Case Mass Estimates and TRL

Integrated Design Capability / Instrument Design Laboratory

Instrument Components	Mass Each (kg)	Qty	Mass Total (kg)	TRL
MLI (15-layers) for Diffuser Wheel Enclosure (0.25 m2)	0.15	1	0.15	9
MLI (15-layers) for UV/Vis/NIR Si CCD Detector Housing Exterior (0.08 m2)	0.0246	1	0.0246	9
MLI (15-layers) for MEB (0.247 m2)	0.148	1	0.148	9
MLI (15-layers) for UV/Vis/NIR Si CCD Digitizers (0.1088 m2)	0.0653	2	0.1306	9
MLI (15-layers) for IMU Sensor (0.461 m2)	0.2768	1	0.2768	9
MLI (15-layers) for IMU Electronics Box (0.218 m2)	0.131	1	0.131	9
MLI (15-layers) for ASC DPU (0.107 m2)	0.064	1	0.064	9
MLI (15-layers) for ASC CHU and Baffles (0.032 m2)	0.019	2	0.038	9
MLI (15-layers) for roll camera (0.658 m2)	0.3948	1	0.3948	9
Thermistors/Platinum RTDs for Telemetry	0.001	30	0.03	9
Thermistors/Platinum RTDs for Heater Control (Redundancy included)	0.001	2	0.002	9
Thermostats for Op Heaters -- Honeywell 3100 Series (Redundancy included)	0.006	96	0.576	9
Thermostats for Survival Heaters -- Honeywell 3100 Series (Redundancy included)	0.006	96	0.576	9
Op Heaters -- Kapton Film 5.5 cm x 6.4 cm (Redundancy included)	0.002	8	0.016	9
Op Heaters -- Kapton Film 20 cm x 20 cm (Redundancy included)	0.0229	48	1.0992	9
Survival Heaters -- Kapton Film 5.5 cm x 6.4 cm (Redundancy included)	0.002	96	0.192	9
Buttons, Velcro and Tape for MLI	0.4	1	0.4	9
Adhesive (STYCAST, Nusil) and Aluminum Tape for Heaters, Thermostats and Thermistors/ Platinum RTDs	0.3	1	0.3	9
Total			20.4621	

Conclusions

- **20 cm long aperture baffle allows 16 hours of continuous science operation**
  - Z307 black paint has 0.96-0.97 absorptance
- **Near 1.0 solar absorptance coating/material may be considered to minimize scattering of sunlight that impinges aperture baffle interior**
- **Passive cooling meets thermal requirement for detectors**
- **Two radiators, one North and one South, for electronics boxes and mechanisms reduces thermal (and possibly mechanical packaging) risk of accommodating a large radiator/sunshade on an unknown spacecraft**
- **Descope case has about 21% larger electronics and mechanisms radiator size/mass, smaller (half) detector radiator size/mass, ammonia CCHPs instead of ethane CCHPs for detector**
  - Ethane CCHP is more expensive

GEO CAPE Filter Radiometer (FR)

~ Concept Presentations ~

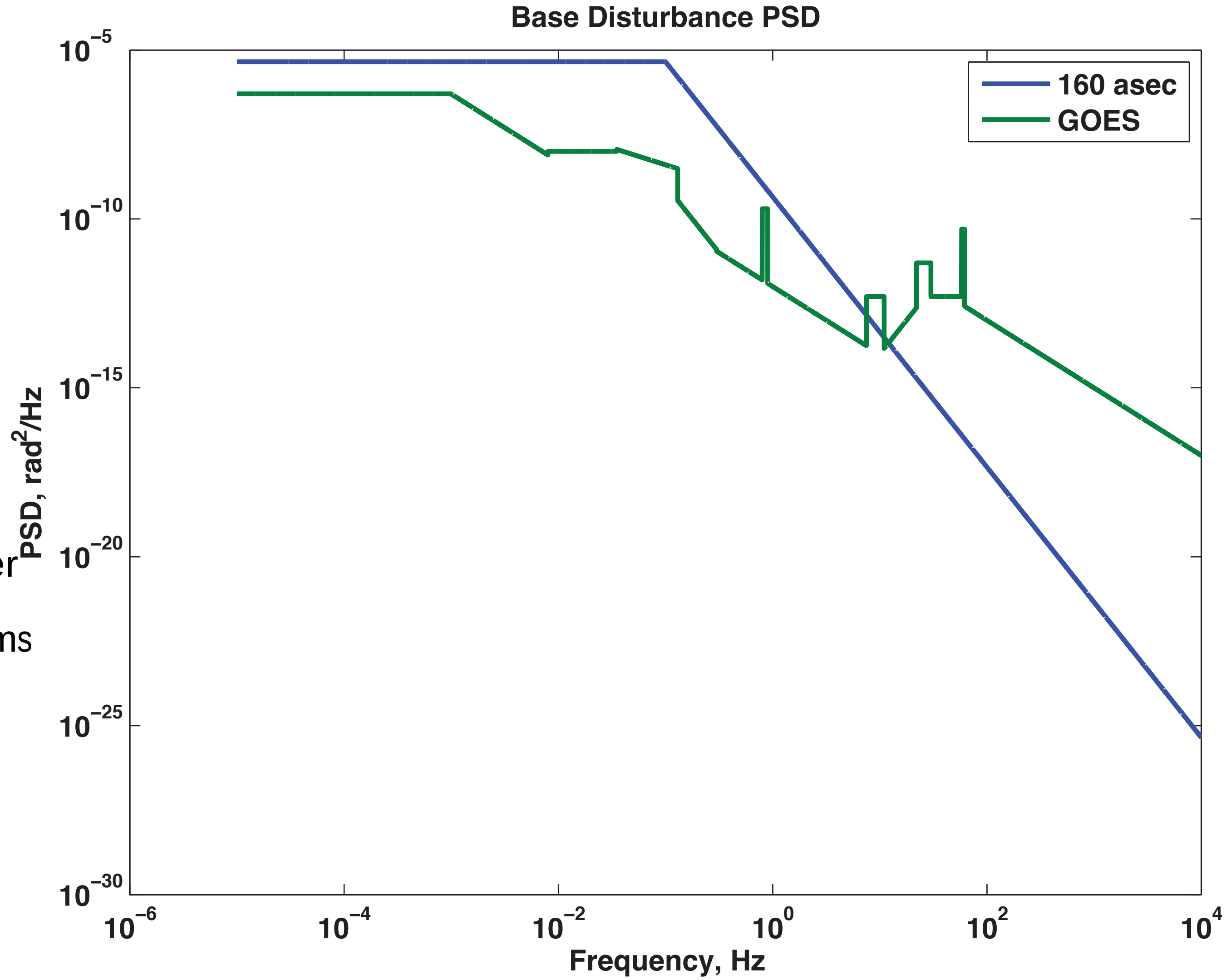
Pointing and Jitter

Eric Stoneking

Aug 12, 2014

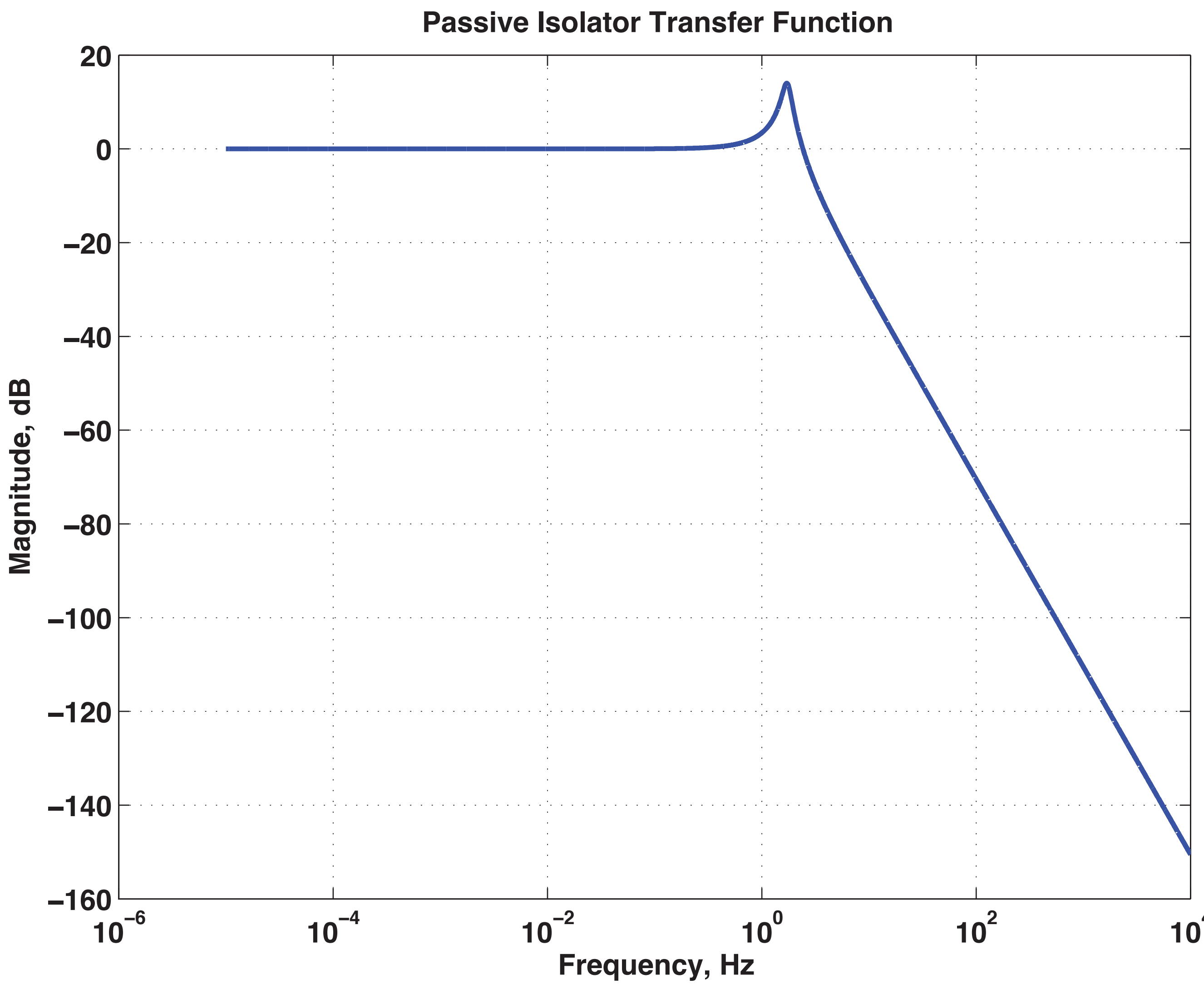
Host Spacecraft Disturbance Spectrum

- **Blue curve is 160-arcsec RMS strawman**
  - Intended to be representative of commercial communications satellites
- **Green curve is envelope of GOES-13 data**
  - Finer low-frequency attitude control
  - More content at higher frequency due to instrument mechanisms



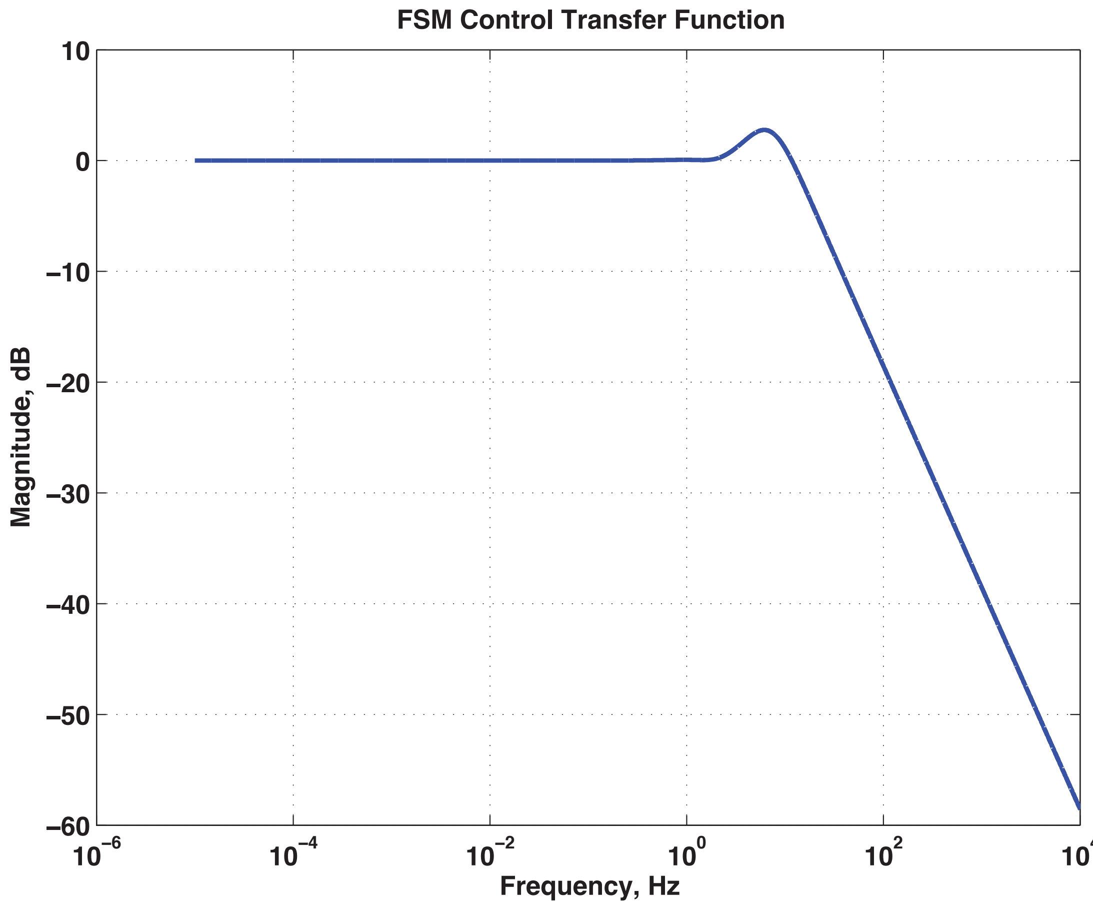
Passive Isolator

- Same design as GEO-CAPE WAS study
- 1.7-Hz bandwidth
- Damping ratio = 0.1
- Second-order roll off (40 dB/decade)



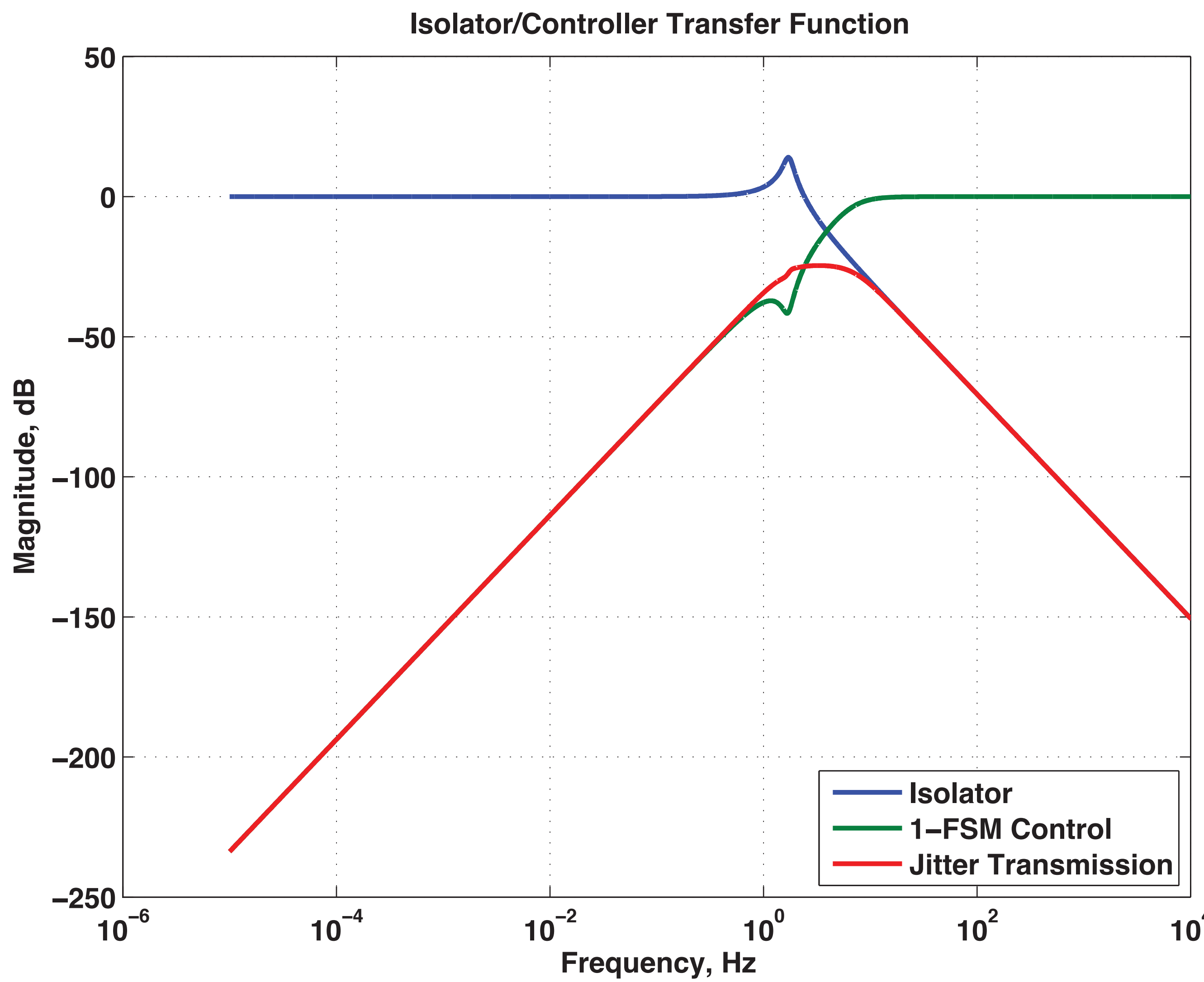
Fast Steering Controller

- **Designed by specifying disturbance transmission transfer function (1-Gc)**
  - Highpass break frequency 7 Hz
  - Notch filter at 1.7 Hz
    - Counters isolator resonance peak
    - Also improves mid-band rejection of base disturbance inputs
- **Plot is resulting Controller transfer function, Gc**
- **Controller Bandwidth (-3dB) is 17 Hz**
  - Requires IMU inputs at ~100 Hz for good estimation



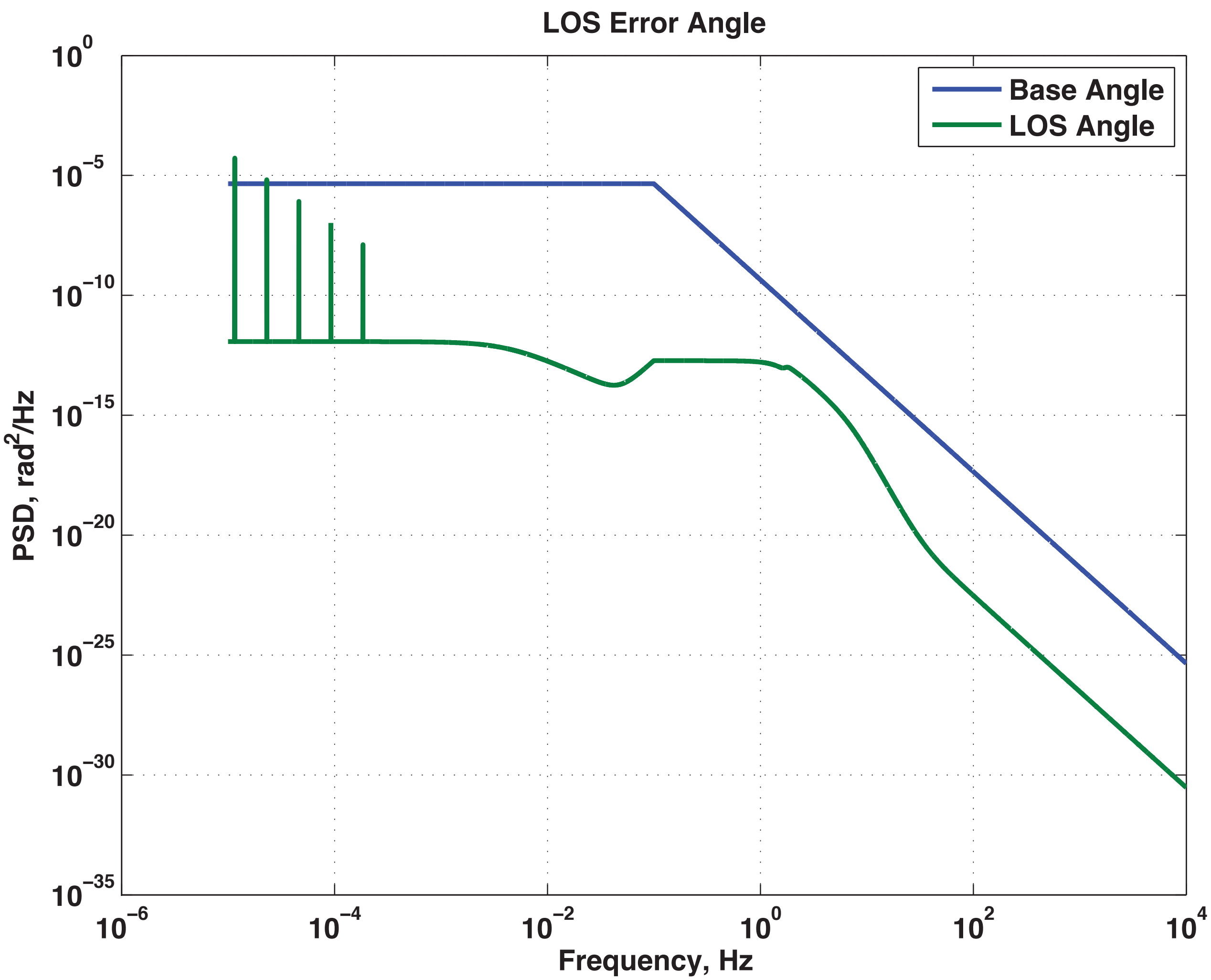
Combined Isolator/Controller Disturbance Transmission

- Isolator rejects high- frequency base motion
- Fast steering loop rejects low-frequency base motion
- Red curve is combination of isolator and fast steering loop



Base Input and LOS Output Spectrum

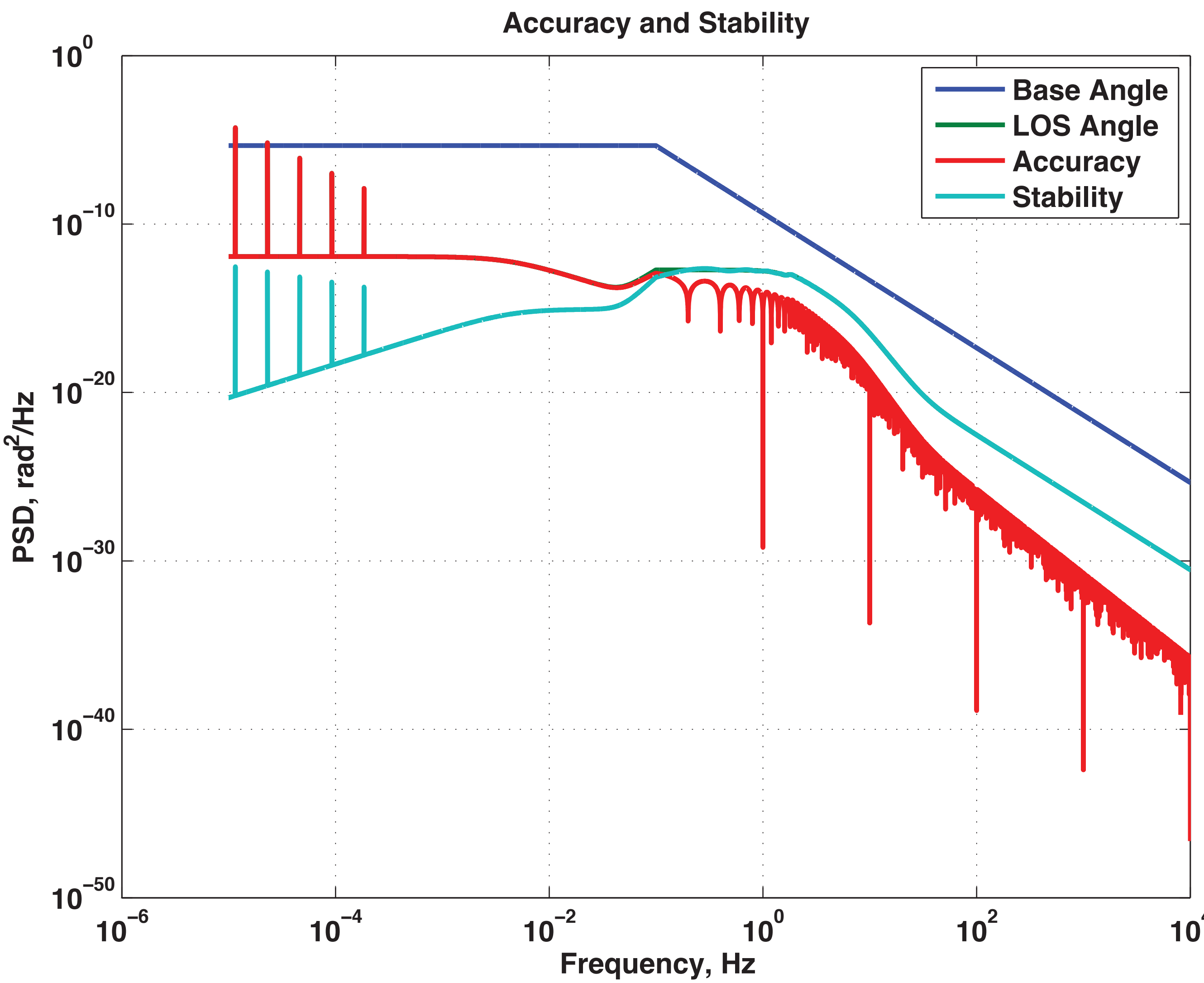
- **Blue curve is 160-arcsec input spectrum**
- **Green curve is Line of Sight spectrum, including**
  - Isolator
  - Fast steering loop
  - Spacecraft position knowledge error
  - Star tracker/IMU attitude observer (on instrument)



Accuracy and Stability Spectra

Integrated Design Capability / Instrument Design Laboratory

- Windowing splits spectrum into "accuracy" (low-frequency) portion and "stability" (high-frequency) portion
- 5-second windowing shown



Performance

- **Pixel size is 250 m on ground**
- **Accuracy requirement**
  - Baseline: 0.25 pixel
  - Threshold: 1 pixel
- **Stability requirement**
  - Baseline: 0.1 pixel
  - Threshold: 0.5 pixel

Pointing Accuracy Capability		
Window (sec)	Response to 160-arcsec Input (arcsec RMS)	Response to GOES Input (arcsec RMS)
0.5	0.284	0.270
1	0.278	0.269
2	0.274	0.269
5	0.271	0.269

Requirement:
0.36 Baseline
1.44 Threshold

Pointing Stability Capability		
Window (sec)	Response to 160-arcsec Input (arcsec RMS)	Response to GOES Input (arcsec RMS)
0.5	0.084	0.016
1	0.105	0.019
2	0.115	0.020
5	0.120	0.019

Requirement:
0.14 Baseline
0.72 Threshold

Conclusion

- **With the assumed input spectra and notional isolation/control design, GEO-CAPE FR pointing accuracy and stability requirements are achievable**
- **Disturbance rejection in mid-frequency band is performance driver**
  - Accomplished by combination of isolator and fast steering loop
- **Fast steering loop requires IMU measurements at ~100 Hz sample rate**
  - Roughly 5x 17-Hz closed-loop bandwidth
  - Fast steering bandwidth may be decreased if isolator resonance is also decreased

GEO CAPE Filter Radiometer (FR)

~ Concept Presentations ~

Flight Software

Kequan Luu
with modifications by JP Swinski

August 12, 2014

Agenda

- Electrical Block Diagrams
- Flight Software Requirements
- Conceptual Architecture
- LOC Estimate for SEER Input
- Summary
- Back up charts (estimates, testing, etc.)

Electrical Architecture
(Baseline, MCT Detector)

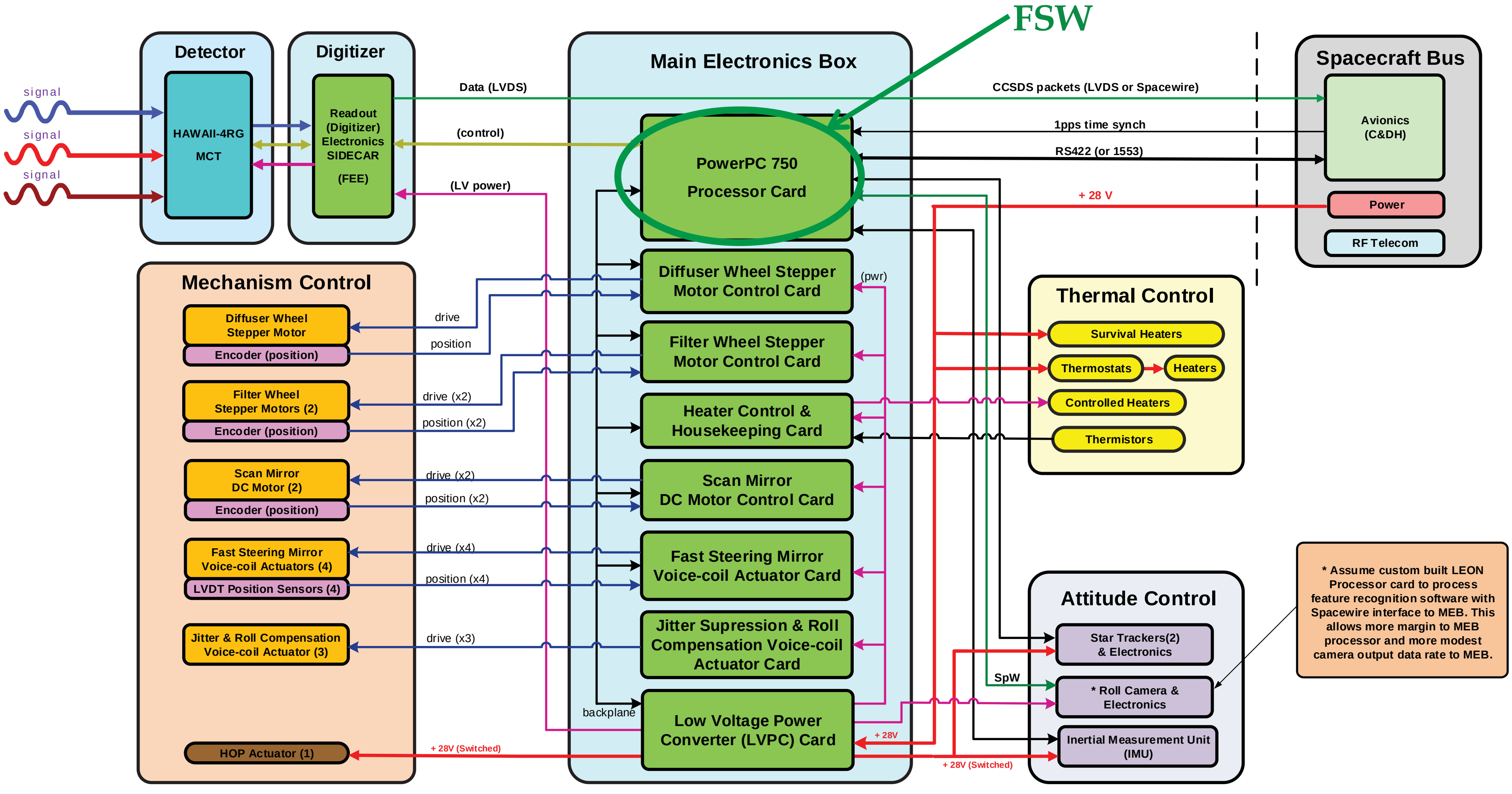


Figure 1.

Recommendations

1. Embed UT700 (Leon3FT) on Roll Camera I/O board

   - Just moving 800KB/s into a Rad750 is not trivial, let alone the processing afterwards

   - Localizing processing on the I/O board minimizes data transfers and offloads an already taxed main processor

   - The UT700 is a system on a chip minimizing board development; it has SpaceWire built in which makes it easier to interface to an LRO/GPM heritage Rad750

   - Dedicating a processor to the roll camera algorithm will allow more flexibility while decoupling the affects of that algorithm on C&DH processing

2. It may difficult to assume a Spacecraft will support 3 independent SpaceWire nodes

   - Even if they do, are they running it through a SpaceWire router, then we need to understand backpressure from a router we don't own

   - Consider running it through LRO/GPM heritage Rad750; even though the router is aged, it is high performance if known issues are worked around

Recommendations

3. Point to point 422 from the Star Trackers and IMU is doable on Rad750 without extra hardware, but it is not ideal.

- **422 hardware on Rad750 is very interrupt intensive**
- **1553 interface would be preferred; it is a less CPU intense, standard interface**
- **this conflicts with potential 1553 command/telemetry interface to Spacecraft; trade that needs to be made**

4. Consider RTEMS over VxWorks

- **Open source platform; community support, no license management, no restriction on development seat distribution, ownership of long term maintenance**

Mission Operations Concept

as documented in the systems presentation

Mode	Function	Frequency	Duration	Mechanism Configuration		
				Diffuser Wheel Mechanism	Scan Mirror Mechanism	FSM
Launch				Closed, Off & Launch Locked	Off & Launch Locked	Off
Standby	Health & Safety, FSW upload, Diagnostic, overnight	Daily	~7 Hours/day	Closed; off	Off	Off
Science	Survey & Targeted	Daily	16 Hours/day	Clear	Move & Stare	On
Cal - Moon	Lunar radiometric cal	When available, 3 to 5/Month	~5 min	Clear	Move & Stare	On
Cal - Sun	Solar radiometric cal	When available, Daily - Weekly	~5 min	Solar Diffuser or Rare Earth Doped	Move & Stare	On
Cal - Star Tracker	Calibrate instrument LOS wrt attitude hardware	Once per hour	Continuously	Any	Move & Stare	On
Cal - Dark	Measure detector dark current and bias	2 x Daily	~5 min	Closed	N/A	N/A

Top-Level Pointing System Diagram

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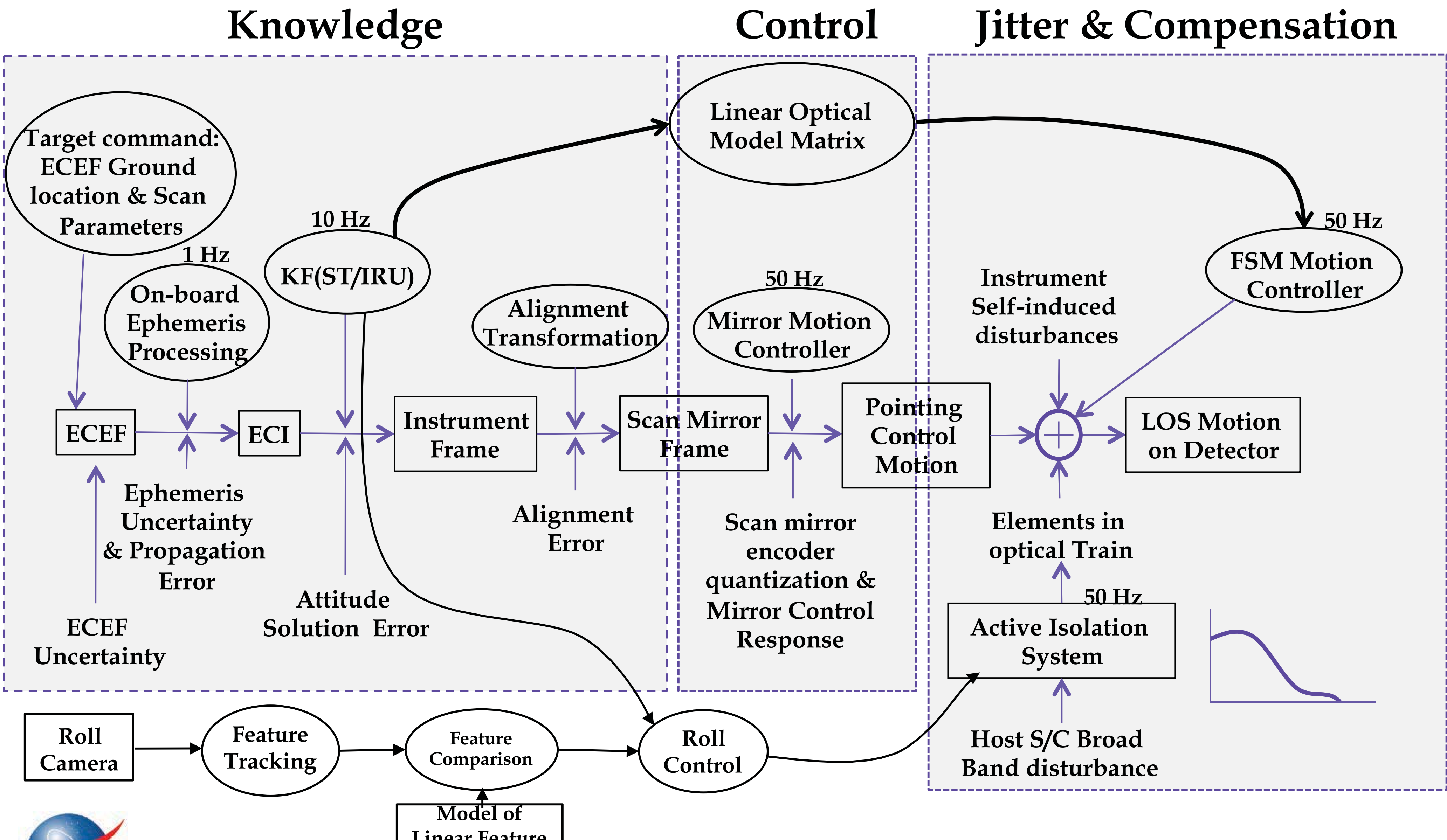
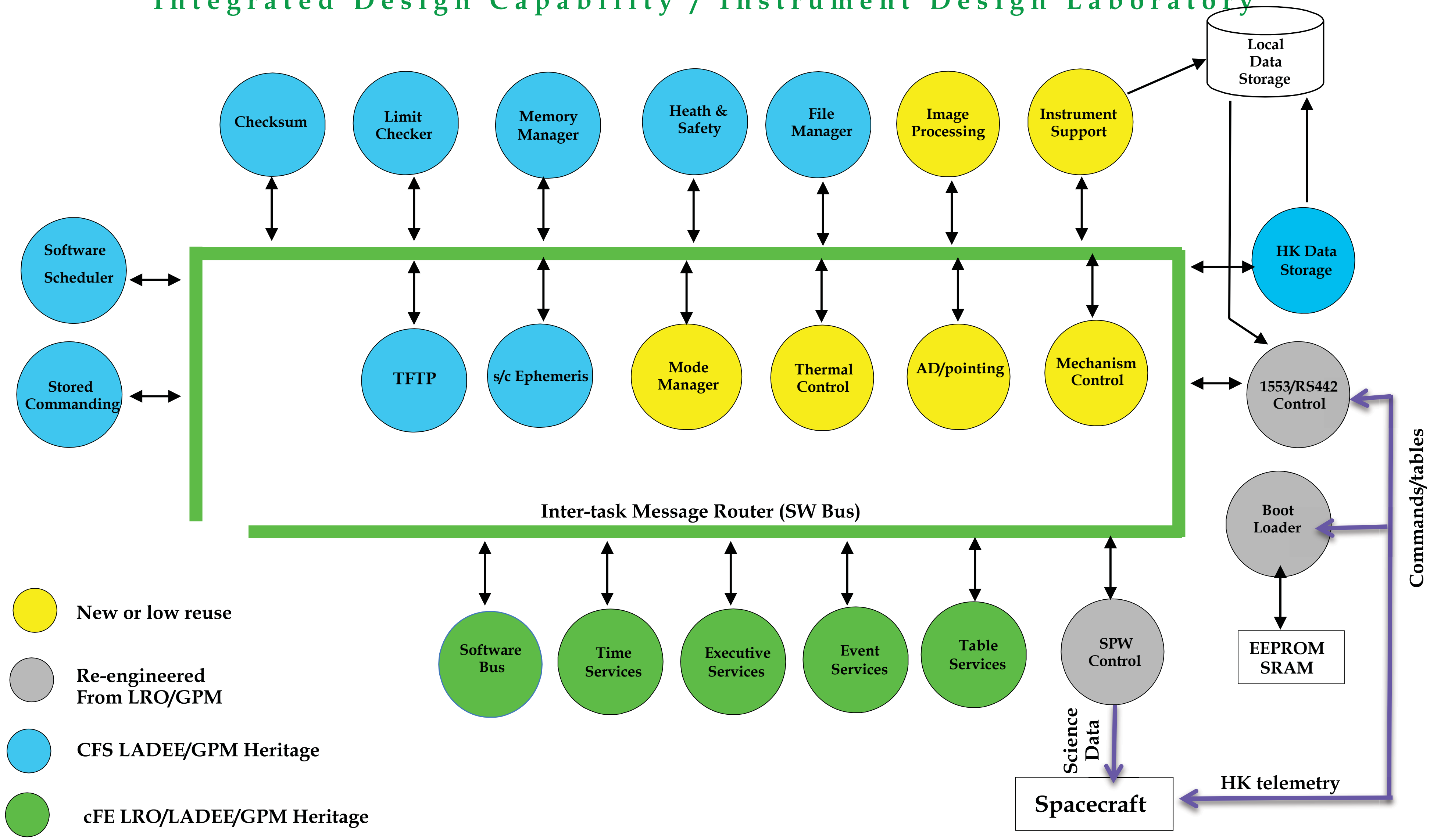


Flight Software Requirements

- Mode management
  - Launch, Standby/Engineering, Calibration, Science, etc.
- Instrument Support
  - Command processing (ST, IMU, Target, etc.)
  - Setup/Control digitizer board (i.e. detectors readout, programmable integration period)
  - SIDECAR Code image storage & management of image download to SIDECAR
  - SIDECAR FSW Management (e.g. memory dump/load/ table updates, etc.)
- Instrument pointing
  - Sensors data processing (ST, IMU, etc.)
  - Roll camera image processing/feature tracking
  - s/c ephemeris propagation
  - AD + Kalman Filter
- Mechanisms control/commanding
  - Scan Mirror @50Hz
  - Fast Steering Mirror @50Hz
  - Diffuser (commanded, 4 positions 90 degree)
  - Active Isolation System @50Hz
  - Filter Wheel management
- PID thermal controllers for the detectors (4x) @1Hz, +/- 0.1k stability
- Time Management – maintain time synch with spacecraft to sub second accuracy
- Collect and CCSDS packetization of HK data including time stamping
- Autonomy (e.g. operations, FDC)
  - Limit Checker (safing, power & thermal monitoring, etc.)
  - Store Command Processor
- Software Management (e.g. memory dump/load, software/table updates, etc.)
- Interfaces
  - 1PPS and time message from Spacecraft
  - 1553/RS422 cmd/data I/F to Spacecraft
  - SpaceWire science data I/F to Spacecraft
  - RS422 to ACS sensors (ST, IMU, Roll camera)
  - Store and forward S/C provided attitude data

- **Derived**
  - VxWork RTOS
  - Bootstrap
  - Health & Safety

Flight SW Architecture



Processor Utilization Estimates

	25	16	MHz Coldfire (effective rate)	BAE750(%)	Updates	60Mhz LRO
	CPU Percentages			Base Value		3.75
Component	**50 Mhz**	**32 Mhz**	**Basis of Estimate**			
cFE	0.12	0.19	LRO B2.5 Measured	0.05		0.19
HK Data Storage	0.12	0.19	LRO B2.5 Measured	0.05		0.19
Memory Manager	0.01	0.02	LRO B2.5 Measured	0.01		0.02
Health & Safety	0.17	0.26	LRO B2.5 Measured	0.07		0.26
Stored Commands	0.10	0.15	LRO B2.5 Measured	0.04		0.15
Limit Checker	0.10	0.15	LRO B2.5 Measured	0.04		0.15
Scheduler	1.46	2.29	LRO B2.5 Measured	0.61		2.29
Checksum	0.48	0.75	LRO B2.5 Measured	0.20		0.75
File Manager	0.02	0.04	LRO B2.5 Measured	0.01		0.04
Mode Manager	0.02	0.04	Estimate	0.01		0.04
1553/RS422 Control	4.80	7.50	Estimate	2.00		7.50
SpaceWire Control	6.00	9.38	Estimate	2.50		9.38
Instrument Support	4.80	7.50	Estimate	2.00		7.50
TFTP	2.40	3.75	Estimate	1.00		3.75
Image Data Processing	76.80	120.00	Estimate	~~32.00~~	0.00	120.00
ACS Orbit Models	4.80	7.50	Estimate	0.50		7.50
AD/Pointing	115.20	180.00	Estimate	12.00		180.00
Mechanisms Control	144.00	225.00	Estimate	15.00	0.01	225.00
Thermal Control	7.20	11.25	Estimate	0.75		11.25
Subtotal	**368.60**	**575.94**		~~68.83~~	36.83	

Filter Manager

~31% Margin

~63 Margin

Onboard Data Processing Assessment (Hazardous Site Identification)

	MIPS	Time required (seconds)
Quad-Core AMD Opteron(tm) Processor 8356	10,500	309
RAD750	240	13,518
GSFC SpaceCube 2.0	5,000	648

Note – assuming the hazard site processing only occurs when CPU cycles are available, it will takes the RAD750 13,518/0.3 = 45,060 seconds = 12.5 hours to process one scene

FSW Development Test eds

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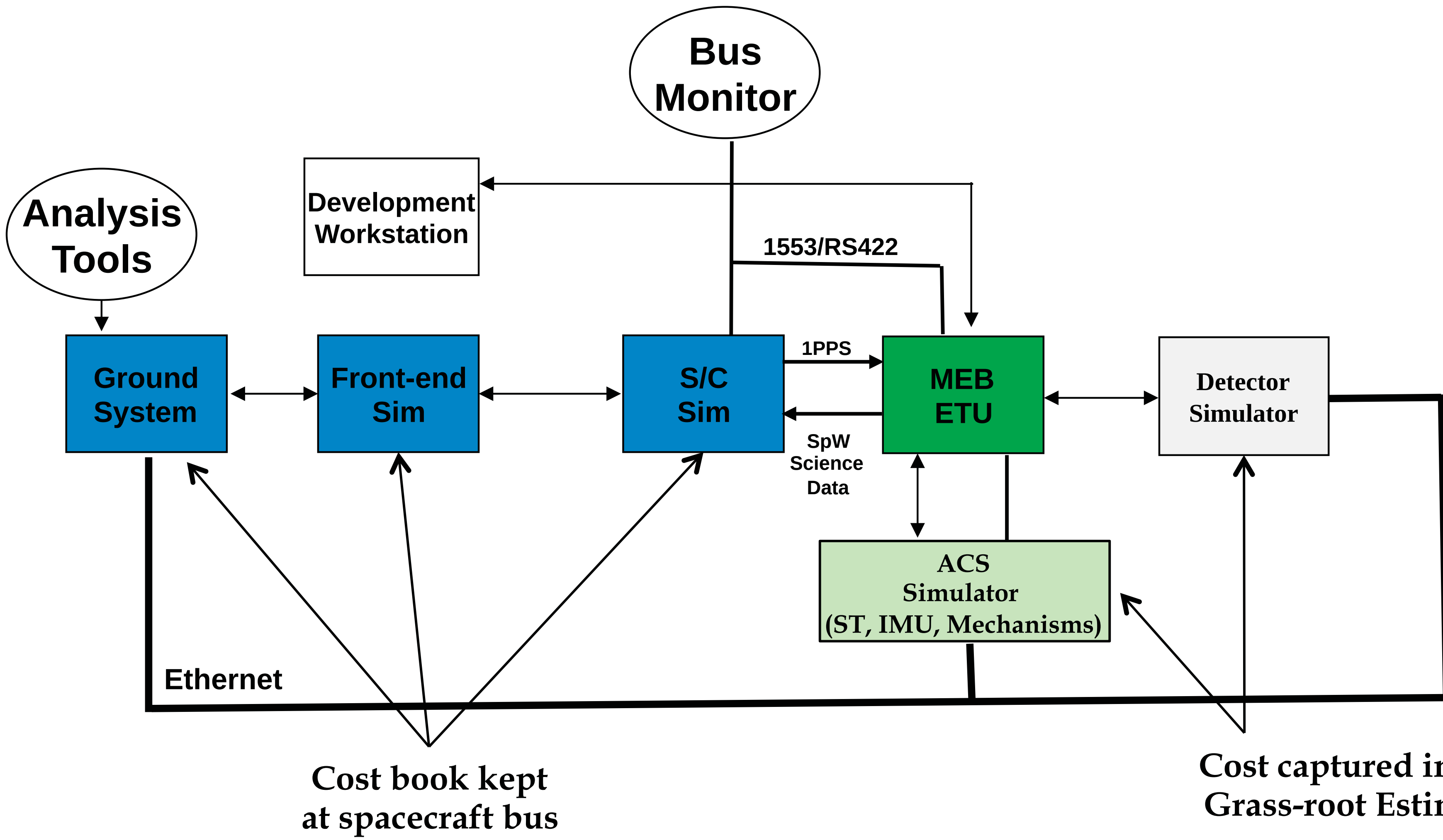


Basis of Cost Estimate

- **FSW development costs estimated using SEER: System Evaluation & Estimation of Resources**
  - Separate modules for Hardware, Software, Integrated Circuits, Manufacturability and Life Cycle
  - NASA-wide site license for SEER managed by Langley Research Center
  - The IDL made in-house assumptions for FSW re-use and labor efforts; the IDL cannot confidently make assumptions about unknown vendor reuse libraries or control measures, or labor efforts or experience, so we apply GSFC reuse and labor assumptions
- **Grassroots test bed costs**
  - FSW test bed simulator software development 3 FTE
  - FSW development tools and test bed GSE $251k
    - $6k for 3 pc
    - $15k for 1553/RS422 bus monitor
    - $180k custom simulator hardware
    - $50k for software development tools and VxWorks
    - The SpW bus monitor/test set is quite expensive and is not needed most of the time, assumed one is available to share with other GSFC projects

SLOC Estimate

Geo Cape WAS Baseline and Delta 2

Information Needed to Begin Software Cost Modeling

BOE: GPM Bld 4.0...RAD750, VxWorks

Spacecraft Bus / Instrument / Ground System: GEO-CAPE 1 MEB FSW

(Complete for each Spacecraft Bus, Instrument, and/or Ground System)

Schedule Information	MMM-YY
Start - Phase A	
CDR	
End - Phase D	
Launch	

Provider (Indicate with 'X')	
GSFC In-House	X
Contractor	
Other (name below)	

Module Name (Hierarchical/Indentured list as appropriate)	Environment (Flight, Ground)	SW type (Control, Data mining, Database, Web, etc.)	Approach (New, Reuse, Rehost, Maintenance, COTS I&T, etc.)	Development Method	Software Lines of Code (Logical)) Total	New	Reuse Total Reuse SLOC	Reuse % Re-engin.	Deleted	% Retest needed on Reuse code	*Nr. Of Stand-alone Programs	**Nr. of I/F with other Modules	Language
*** OS API & OSAL	Flight	OS/Executive	Modification, Minor	Waterfall	2338	200	2138	20%	0	80	0	5	c
*** Boot Loader	Flight	Flight System	Modification, Minor	Waterfall	1868	100	1768	20%	0	100	1	0	c
*** BSP	Flight	Flight System	Reengineering, Major	Waterfall	1492	300	1192	20%	0	80	0	0	c
*** Executive Services	Flight	OS/Executive	Integrate /w config	OTS integration	4737	0	4737	10%	0	10	1	5	c
*** Event Service	Flight	Flight System	Integrate /w config	OTS integration	1429	0	1429	10%	0	10	1	5	c
File System	Flight	Flight System	Integrate /w config	OTS integration	763	0	763	10%	0	10	0	5	c
*** Mission Config Include Files	Flight	Flight System	Reengineering, Major	OTS integration	1857	1200	657	80%	0	100	0	0	c
*** Software Bus	Flight	Flight System	Integrate /w config	OTS integration	2017	0	2017	10%	0	10	1	5	c
*** Table Service	Flight	Flight System	Integrate /w config	OTS integration	2182	0	2182	10%	0	10	1	5	c
*** Time Service	Flight	Flight System	Integrate /w config	OTS integration	1941	0	1941	10%	0	10	1	5	c
*** cFE Configuration (hdr files)	Flight	Flight System	Integrate /w config	OTS integration	226	0	226	10%	0	10	0	0	c
*** cFE platform Support Pkg	Flight	Flight System	Reengineering, Major	Waterfall	827	200	627	50%	0	100	0	5	c
CFS Library	Flight	Flight System	Integrate /w config	OTS integration	166	0	166	0%	0	0	0	0	c
Checksum	Flight	Flight System	Integrate /w config	OTS integration	2811	0	2811	10%	0	10	1	1	c
File Manager	Flight	Flight System	Integrate /w config	OTS integration	1664	0	1664	10%	0	10	1	1	c
File Commanding	Flight	Flight System	Integrate /w config	OTS integration	447	0	447	10%	0	10	1	1	c
Health & Safety	Flight	Flight System	Integrate /w config	OTS integration	1433	0	1433	10%	0	10	1	1	c
Memory Manager	Flight	Flight System	Integrate /w config	OTS integration	1927	0	1927	10%	0	10	1	1	c
Scheduler	Flight	Flight System	Integrate /w config	OTS integration	1067	0	1067	10%	0	10	1	1	c
Limit Checker	Flight	Flight System	Integrate /w config	OTS integration	1742	0	1742	0%	0	10	1	1	c
Limit Checker Configuratoin	Flight	Flight System	Modification, Major	Waterfall	300	200	100	40%	0	100	0	1	c
Store Command Processor	Flight	Flight System	Integrate /w config	OTS integration	1625	0	1625	10%	0	10	1	1	c
Housekeeping	Flight	Flight System	Reengineering, Major	Waterfall	554	300	254	80%	0	50	1	1	c
Command Ingest	Flight	Flight System	Modification, Major	Waterfall	1721	400	1321	20%	0	60	1	1	c
Telemetry Output	Flight	Flight System	Modification, Major	Waterfall	3067	800	1767	30%	500	60	1	1	c
TFTP	Flight	Flight System	Modification, Major	Spiral	1678	100	1578	30%	0	80	1	1	c
Instrument Support	Flight	Flight System	Reengineering, Major	Waterfall	1800	1500	300	80%	0	80	1	1	c
Mechanism Control	Flight	Flight System	Modification, Major	Waterfall	3000	2000	1000	90%	0	100	1	1	c
Filter Table Control	Flight	Flight System	Modification, Major	Waterfall	1500	1500	0	0%	0	100	1	1	c
Image Processing	Flight	Flight System	Modification, Major	Waterfall	2000	1800	200	90%	0	100	1	1	c
Ephem	Flight	Flight System	Integrate /w config	OTS integration	155	0	155	0%	0	10	1	1	c
AD/Pointing	Flight	Flight System	Modification, Major	Waterfall	3000	1000	2000	80%	0	100	1	1	c
Thermal Control	Flight	Flight System	Modification, Minor	Waterfall	300	100	200	30%	0	60	1	1	c
Mode Manager	Flight	Flight System	Reengineering, Major	Waterfall	800	400	400	60%	0	80	1	1	c
C&DH Library	Flight	Flight System	Integrate /w config	OTS integration	4267	0	4267	0%	0	10	1	1	c
Math Library	Flight	Flight System	Integrate /w config	OTS integration	1123	0	1123	0%	0	10	1	1	c
GNC Application Framework	Flight	Flight System	Integrate /w config	OTS integration	1041	0	1041	0%	0	10	1	1	c
FSW Tables (ex: SC & filter Table	Flight	Flight System	New	Waterfall	2500	2000	500	100%	0	100	1	1	c
*** Bus Control	Flight	Flight System	Modification, Minor	Spiral	3947	500	2447	50%	1000	100	1	1	c
Total SLOC					*65812*	*14600*	*51212*						
							78%	*Reuse*					

*** Mission Critical Components

* Nr. of Stand-alone Programs (Programs included in SLOC/size estimate): default is SLOC / 500.

** Nr. Of I/F with other Modules (Concurrent integration): default is 5.

All Modules require 100% Retest, unless no SLOC development (New, Reuse, or Deleted) which assumes 10% Retest required

Designed for reuse

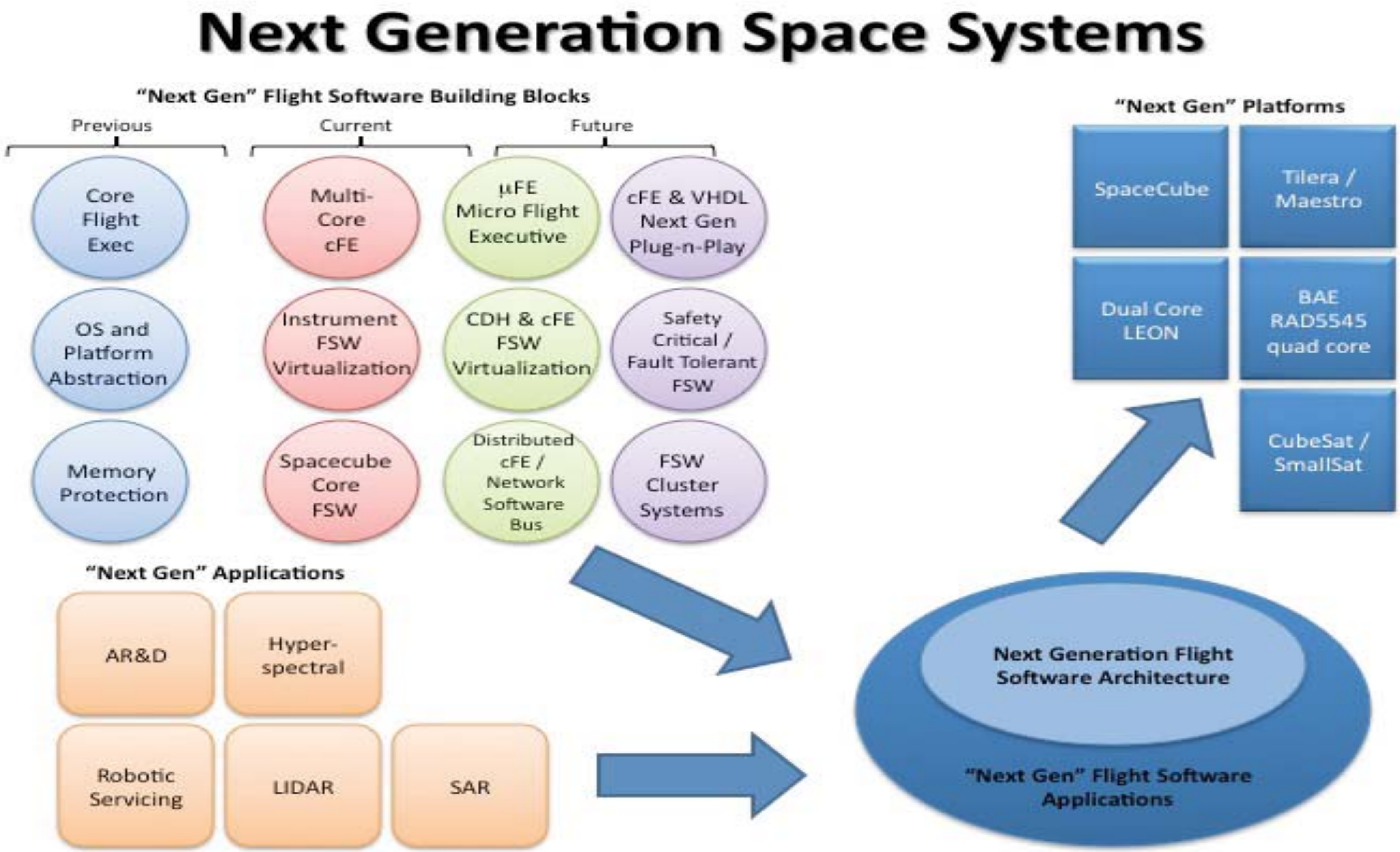
Summary and Recommendations

- **Line Of Code estimation shows ~80% code reuse for MEB**
  - **High heritage based on GSFC CFS approach**
  - **An implementation at another Center or at an experienced Vendor should also take advantage of reuse algorithms, but the specific ratio should be evaluated**
  - **No technical show-stoppers**

- **Significant flight computational resources are needed If additional science data processing/reduction is to be implemented onboard (i.e. hazardous site identification). Flight computing options:**
  - Spacecube 2.0: GSFC developed, older version demonstrated on ISS
  - Maestro: maximum 7x7 = 49 cores; the team is working on a 4x4 flight version
  - Xilinx Virtex 7: capable of hosting many ARM processor cores. 587 is working to get a prototype board
  - BAE RAD5545 Quad Core
  - NASA/DoD recently put out a RFP for high performance computing technology development
  - Recommendation: benchmark the ~~Image Data Processing~~ and the Hazard Site Identification algorithms on a RAD750 and on a Spacecube 2.0
  - Recommendation: benchmark the Image Data Processing on UT700 (Leon3FT)

582/587 Technology Road Map

Integrated Design Capability / Instrument Design Laboratory



SpaceCube 2.0 Use Cases

On-Board Processing
- Data Volume Reduction
- Image Processing
- Autonomous Operations
- Product Generation
- Event / Feature Detection
- Real-time / Direct Broadcast
- Docking / Servicing
- Compression
- Calibration / Correction
- Classification
- Inter-platform collaboration

Hybrid Science Data Processing
- CPU
- FPGA
- DSP

GSFC SpaceCube On-Board Processor
- 10x-100x computing performance
- Lower power (MIPS/watt)
- Lower cost (commercial parts)
- Radiation tolerant (not hardened)
- Software upset mitigation

Lower FSW heritage than RAD750 base

Processor Comparison

	MIPS	Power	MIPS/W
MIL-STD-1750A	3	15W	**0.2**
RAD6000	35	10-20W	**2.33**1
RAD750	300	10-20W	**20**2
SPARC V8	86	1W3	**86**3
LEON 3FT	60	3-5W3	**15**3
GSFC SpaceCube 1.0	3000	5-15W	**400**4
GSFC SpaceCube 2.0	**5000**	**10-20W**	**500**5

Notes:

1 – typical, 35 MIPS at 15 watts

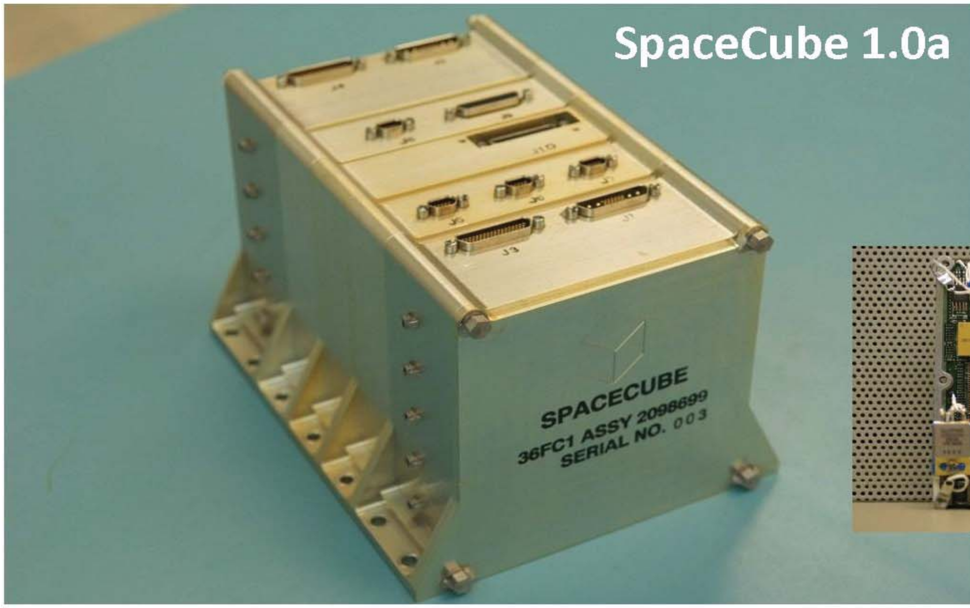
2 – typical, 300 MIPS at 15 watts

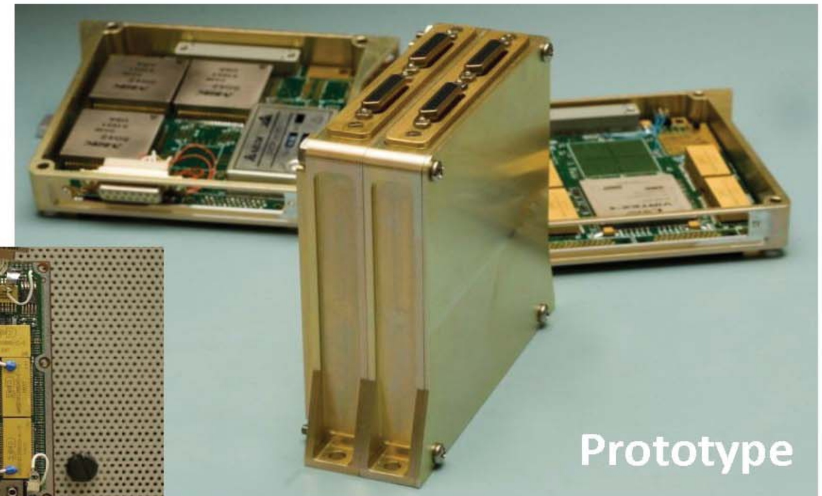
3 – processor device only ... total board power TBD

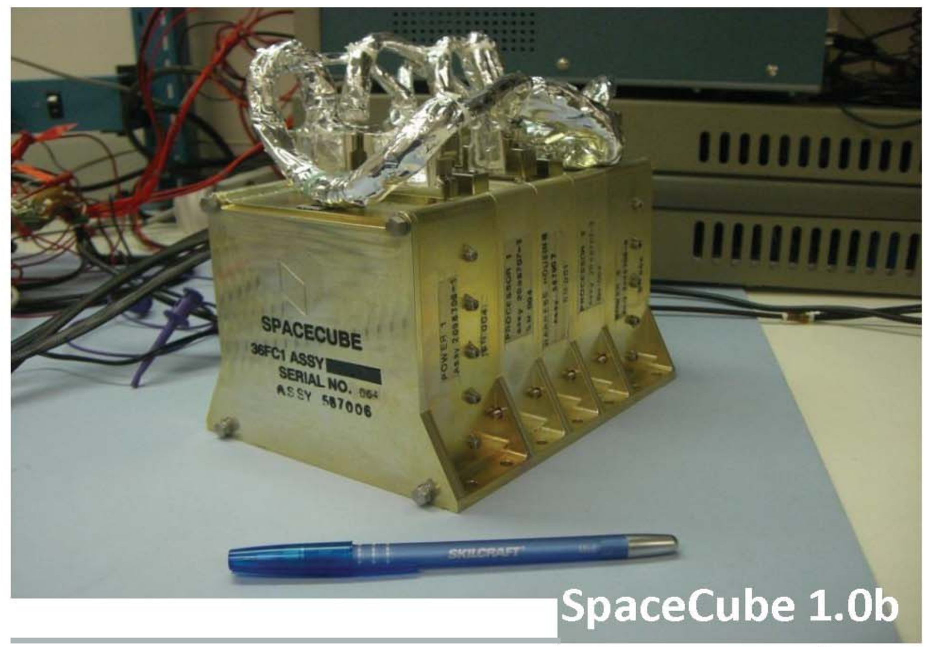
4 – 3000 MIPS at 7.5 watts (measured)

5 – 5000 MIPS at 10 watts (calculated)

Current SpaceCube Systems







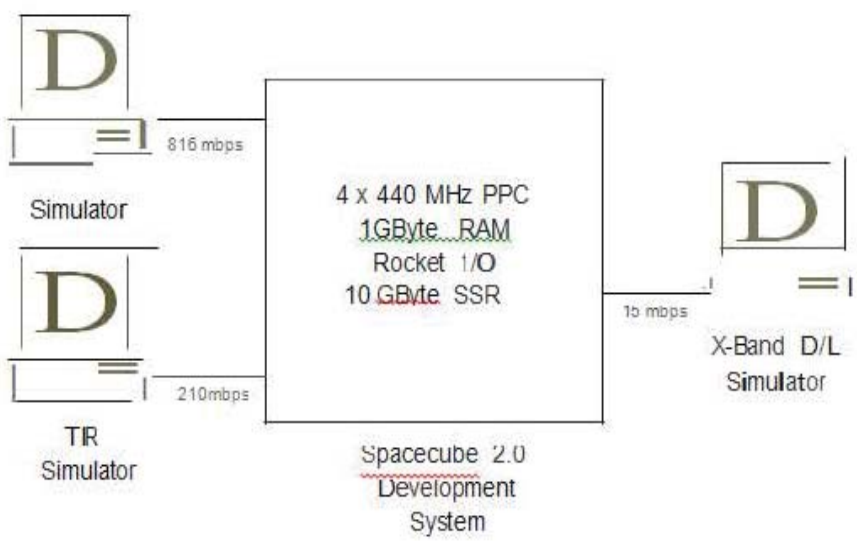
SpaceCube Family Overview

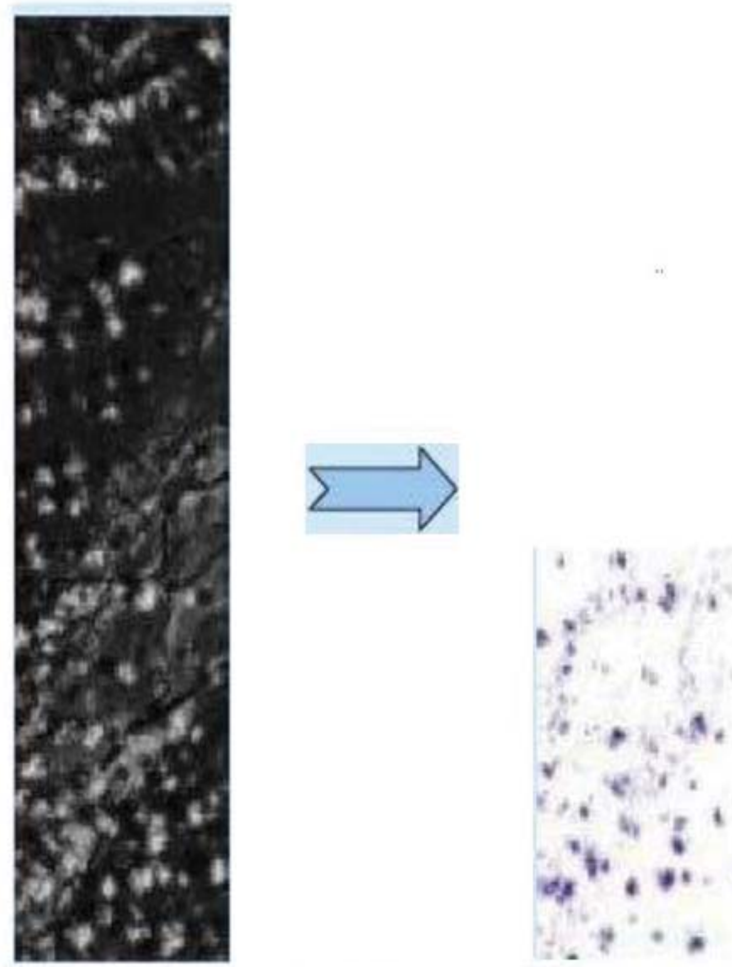
Integrated Design Capability / Instrument Design Laboratory

Unit	Mission	Notes	Specs	Stats	Status
SpaceCube 1.0a	Hubble Servicing Mission 4	Relative Navigation Sensors Experiment STS-125 May 2009	4"x4" card (2) Virtex4	Size: 5"x5"x7" Wt: 7.5 lbs Pwr: 37W	2009 Flight
SpaceCube 1.0b	MISSE-7 (ISS)	added RS-485, RHBS, STS-129 Nov 2009	4"x4" card (2) Virtex4	Size: 5"x5"x7" Wt: 7.5 lbs Pwr: 32W	In Flight
SpaceCube 1.0c	DEXTRE Pointing Package (ISS)	Original RNS unit, w/added 1553 & Ethernet	4"x4" card (2) Virtex4	Size: 5"x5"x7" Wt: 7.5 lbs Pwr: 40W	Final stages of Implementation
SpaceCube 1.5	SMART (DoD/ORS)	adds GigE & SATA, commercial parts, sounding rocket flight	4"x4" card (1) Virtex5	Size: 5"x5"x4" Wt: 4 lbs Pwr: < 20W	
SpaceCube 2.0	Earth/Space Science Exploration missions	Std 3U form factor, GigE, SATA, Spacewire, cPCI	4"x6" card (2) Virtex5 (1) SIRF	Size: 5"x5"x7" Wt: < 10 lbs Pwr: 20-40W	Under Development
SpaceCube 2.0 Mini	CubeSats, Sounding Rocket, UAV	"Mini" version of SpaceCube 2.0, CubeSat form factor	2.5"x2.5" card (1) Virtex5/SIRF	Size: 3.5"x3.5"x3.5" Wt: 3 lbs Pwr: <10W	

HyspiRI Demonstration Testbed

HyspiRI SpaceCube IPM Testbed





Cloud Classifier

SpaceCube 2.0 Processor Card

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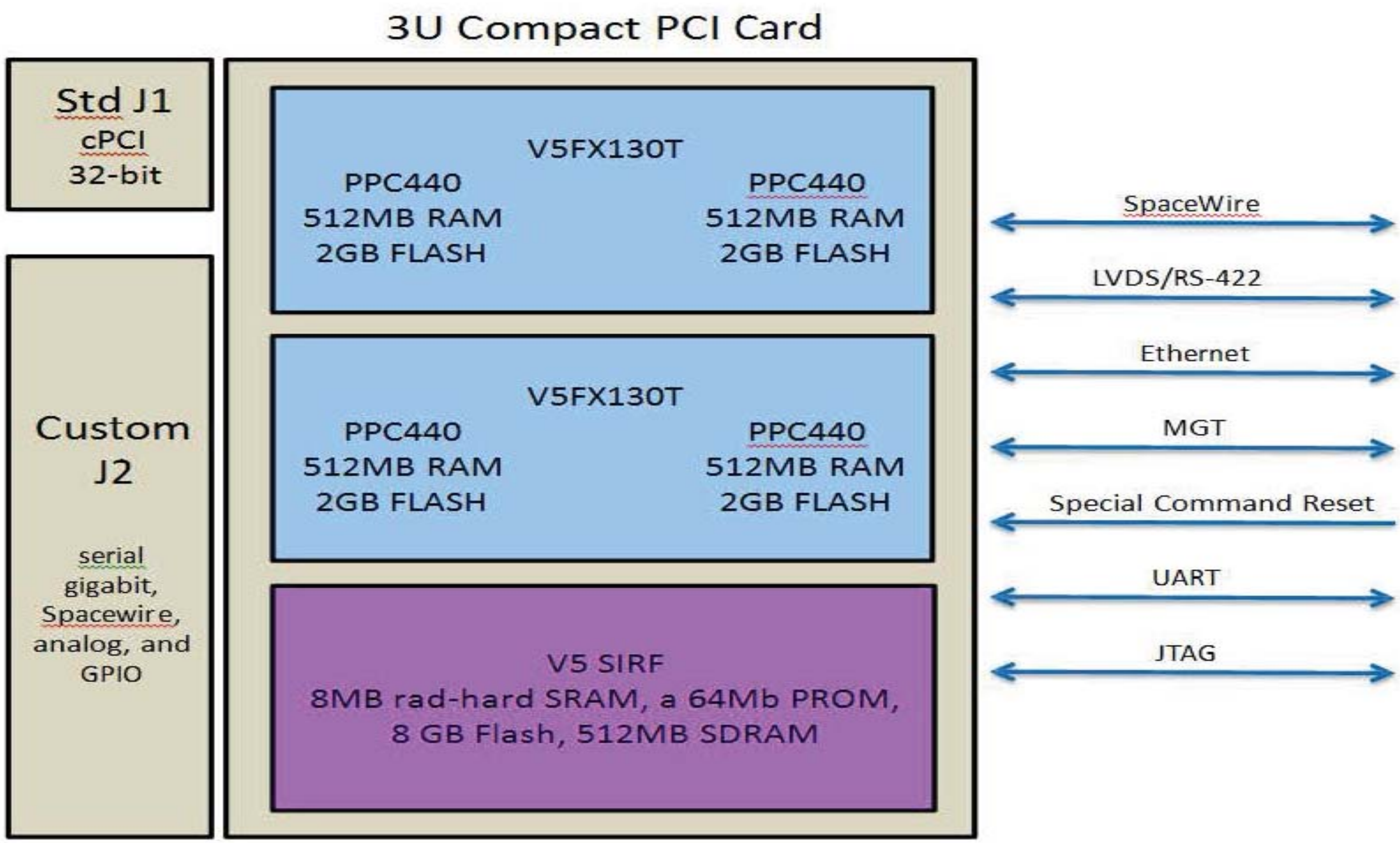

System	EDU	FLT	Notes
1.0	$500K	$850K	RNS configuration
1.5	$200K	N/A	All commercial parts
2.0	$640K	$1.1M	
Mini	$300K	$600K	Best guest for now

SpaceCube 2.0
Data & Processing Flow Diagram

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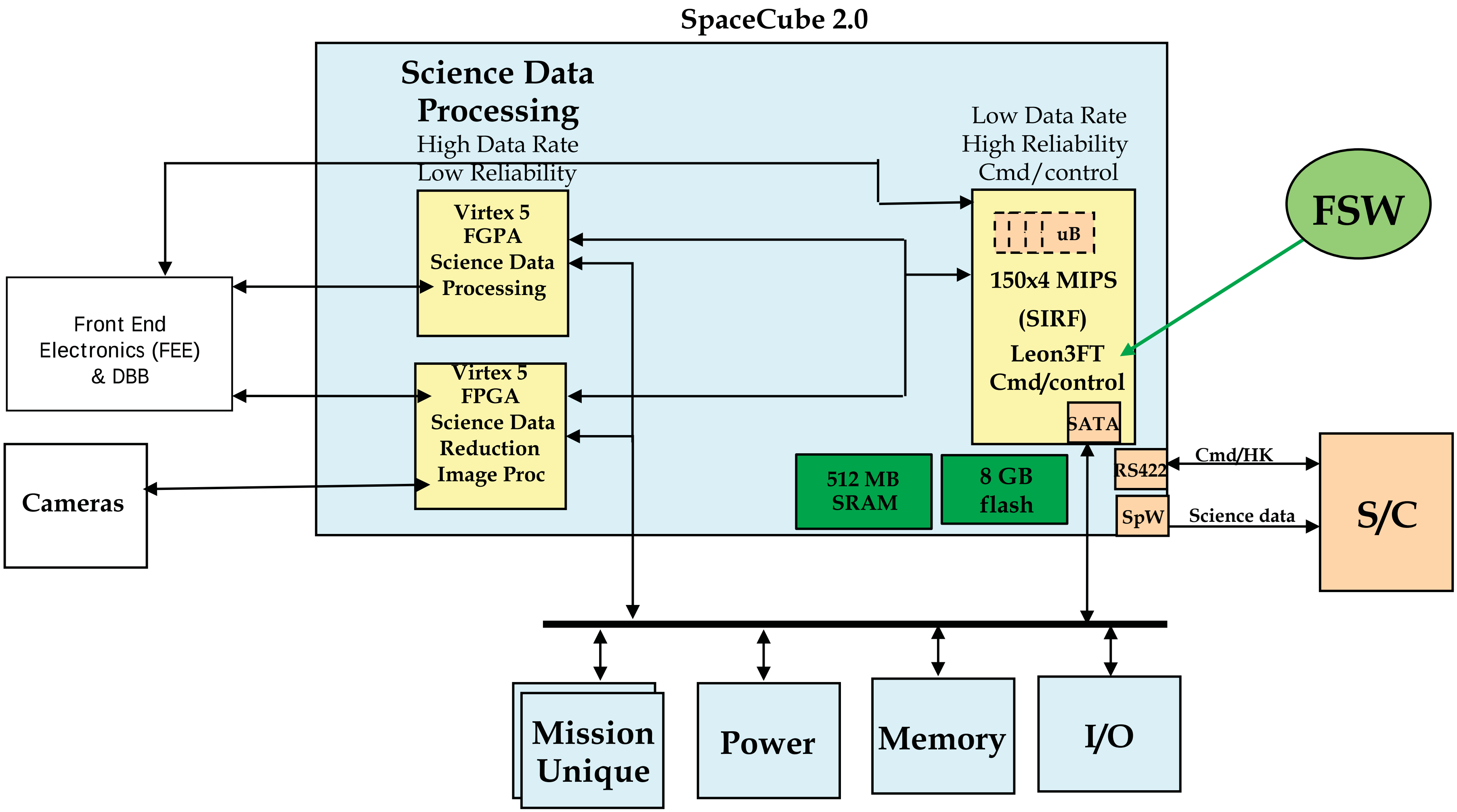


Backup Slides

- **Development Approach**
- **Management Approach**
- **Verification & Validation**

FSW Development Approach

- **Reuse LRO/GPM C&DH FSW (Med to high heritage, low risk - LRO launched 2009, GPM launch 2014)**
  - LRO/GPM FSW Features (based on 582's Core Flight Executive)
    - Developed using FSW best practices consistent w/NPR 7150.2
    - Onboard file systems and associated file transfer mechanisms
    - Onboard networks with standard interfaces
    - Standard application interfaces (API) for ease of development and rapid prototyping
    - Dynamic application loading, middleware (SB) provide dynamic cmd/tlm registration
    - POSIX APIs and open source Integrated Development Environment
  - Benefits
    - Will enable parallel collaborative development and system interoperability
    - Will automate many previously manual development activities
    - Will simplify technology infusion and system evolution during development and on-orbit
    - Will enable rapid deployment of low cost, high quality mission software

- **Reengineer LRO/GPM FSW for all mission specific components**
  - Mission-specific ops concept support, thermal electronics, etc.

Management Approach

- **Product Development Process Will Comply with NPR 7150.2 (NASA Software Engineering Requirements and GOLD Rule)**
- **Development**
  - Product Development Plan per 582 branch standards, approve by Branch & Project
  - Detailed FSW development schedule integrated with project & subsystems schedules
  - Requirements management using MKS tool
  - Monthly PSR with AETD & project; branch status reviews
  - Weekly system engineering meetings, FSW team meetings
  - FSW Design & Code reviews
  - Major milestones (SCR, PDR, CDR, etc)
- **Configuration Management**
  - FSW CM Plan per 582 branch standards, approve by Branch & Project
  - Commercial CM tool (i.e., MKS) to manage source codes and document
  - Proposed FSW changes affecting missions requirements, cost and/or schedule will be forwarded to Project level CCB
- **Test Plan**
  - FSW Test Plan per 582 branch standards, approve by Branch & Project

FSW Verification and Validation

- **Unit Test**
  - Done by developers using PC tools
  - Follow Branch 582 Unit Level Test Standard - Tailored
  - Includes Path testing, Input/Output testing, Boundary testing, and Error Reporting verification
  - Occasionally BB H/W is required to verify H/W I/F
- **Build Integration Test**
  - Done by developers to verify that the FSW performs properly on the BB H/W in the FSW testbeds using embedded system tools
  - First level functionality ensured for integrated software
  - Build Test Team to assist in GSE I/F checkout
- **Build Verification Test**
  - Done by independent test team with Science Team support on the BB H/W in the FSW testbeds using embedded system tools
  - Test each requirement in the Flight Software Requirements documents (where possible at the build level)
  - Use test scenarios to test requirements in both a positive and negative fashion.
  - Scenarios constructed to combine requirements that are logically connected to create a test flow.
  - Automation to be utilized as much as possible
  - Requirements Traceability Matrix maintained

GEO CAPE Filter Radiometer (FR)

~ Concept Presentations ~

Contamination

Mark Secunda

Aug 12, 2014

Filter Radiometer

- **Key Parameters:**
- **Geostationary**
- **Commercial Satellite**
- **Covers wavelengths from 350-1050 nm**
- **10% throughput loss acceptable**

		(SZA = 70°)				
λo - nm	$\Delta\lambda$ - nm	W/m^2-$\Delta\lambda$um-ster		Req'd		
Bands	FWHM	Ltyp	Lmax	SNR_{req}	Required Minimum Set of Multi-Spectral Bands[1]	NOTES
350	15	46.90	166.2	1,000		
360	10	45.40	175.6	1,000	Yes	
385	10	38.40	177.9	1,000	Yes	
412	10	49.50	281.1	1,000	Yes	
425^	0.8	48.20	277.0	500		For estimating SNR for NO2 retrievals
443	10	45.00	271.3	1,000	Yes	
460	10	41.90	266.0	1,000		
475	10	38.20	261.3	1,000		
490	10	34.90	256.6	1,000	Yes	
510	10	29.00	250.3	1,000	Yes	
532	10	23.30	243.4	1,000		
555	10	18.50	224.9	1,000	Yes	
583	10	15.30	227.4	1,000		
617	10	12.20	216.7	1,000	Yes	
640	10	10.50	209.5	1,000		
655	10	9.57	204.7	1,000		
665	10	9.17	201.6	1,000	Yes	
678	10	8.66	197.5	1,000	Yes	
710	10	6.95	187.5	1,000	Yes	
748	10	5.60	175.5	600	Yes	
765	40	5.25	170.2	600	Yes	
820	15	3.93	152.9	600		
865	40	2.77	138.8	600	Yes	
1020	40	1.48	109.1	450	Yes	
1245*	20	0.582	56.10	250		
1640*	40	0.178	19.70	180		
2135*	50	0.040	5.35	100		

[1] Additional bands between 360-1020nm desirable; SNR should not be an issue for the additional bands.
^ Pixels can be aggregated up to 3x3 to achieve required SNR of 500:1 for atmospheric NO2 retrievals
* Pixels can be aggregated up to 2x2 to achieve required SNR

FR Concerns

- **Commercial satellite I&T not done to the same cleanliness standards as we're used to.**
  - The FR instrument will need extra protection against unknowns
    - Well sealed instrument
    - Aperture one-time deploy cover
    - Purge
      - Likely a special request - often not used at all for commercial satellites
  - Lack of satellite contamination requirements may affect radiator EOL values
  - Need to confirm nothing is in the line of sight to aperture
- **Large wavelength band means sensitivity to lots of materials**
- **Medium number of optics and surfaces**
  - Bake outs may be required
    - Will help with consistency
    - Some margin available for satellite unknowns
- **Electrostatic Return (ESR) of contamination can be a problem if the host spacecraft and instrument aren't completely grounded**

FR Wavelength Sensitivity

- **Baseline**
  - Detector range 350-1640 nm
  - 10 optical surfaces
  - 1 cryo MCT detector (185K range)
  - Estimate for 10% throughput loss, launch to end-of-life, is ~580 Angstroms per surface, and ~360 Angstroms for the detector
    - Good contamination margin on optics, reasonable margin on detector
- **Delta**
  - Detector range 350-1050 nm
  - 10 optical surfaces
  - 1 Silicon detector (293K range)
  - Estimate for 10% throughput loss, launch to end-of-life, is ~480 Angstroms per surface, and ~480 Angstroms for the detector
  - Good contamination margin on optics and detector

Effects on Processes

- **Multiple optics with limited throughput loss means more care**
  - bake-outs for internal components
  - Clean bench use for subassemblies, clean rooms for assemblies
- **Sealing required to protect against possibly unclean spacecraft build**
- **Sealing detector should help, but presents its own contamination challenges**
- **May not allow spacecraft level testing with aperture open**
- **Instrument purge**
  - Cost, complexity, schedule impacts

Conclusions

- **Internally, nothing unusual**
- **A somewhat contamination sensitive instrument on a satellite with no contamination concerns, and no ability to enforce requirements, is problematic.**
  - A well sealed instrument should mitigate this.
  - Large allowable throughput loss (10%) and warm detector helps

GEO CAPE Filter Radiometer (FR)

~ Concept Presentations ~

Reliability

Aron Brall

Aug 12, 2014

Reliability Requirements

- **Success criteria**
  - Class C mission
  - 3 year mission requirement with an Instrument Probability of Success (Ps) of 0.85 or greater at 3 years
  - 5 year mission goal
  - 2 Configurations – Baseline and Descope
- **Reliability Assurance**
  - Designs are validated with appropriate Reliability Analyses – FTA, FMEA, Parts Stress Analysis, PRA, etc
  - Parts are Level 3 (Class S or Class B upscreened to requirements of EEE-INST-002 for Level 3 parts)
- **Designs meet NASA and GSFC specifications including:**
  - EEE-INST-002
  - GEVS (GSFC-STD-7000: General Environmental Verification Standard)
  - GSFC Gold Rules (GSFC-STD-1000)
  - NPR-8705-4

Reliability Assumptions - 1

- **Component lifetimes follow the exponential distribution except bearings and gears which are modeled using the Weibull distribution**
- **The following are considered non-credible single point failures (SPF):**
  - Structural and non-moving mechanical components
  - Short or open on power bus
  - Flexure Failures
  - Optical Failures (non active components)
- **Software and procedural failures are not included in the analysis**
  - Software is modeled as reliability of 1
  - Software Reliability needs to be formally addressed in development process
    - Software can have as low as 80% Reliability if this is not seriously addressed
- **Standby (Idle Time) Reliability was not addressed**
- **Reliability of Host Spacecraft and Launch Vehicle were not assessed**

Reliability Assumptions - 2

- **Exact models were used to determine subsystem reliabilities**
  - Binomial models for k of n subsystems:
    - Detector and Roll Camera Arrays
      - 4055 of 4096 rows for 4096 X 4096 detector
      - 3000 of 3072 rows for 4096 X 3072 Roll Camera sensor
  - Hot Standby Redundant exponential models for:
    - Operational and Survival Heater Circuits
  - All other components are Single String

Reliability Assumptions - 3

- **Bearing loads on rotating assemblies are loaded to their recommended preloads per manufacturers recommendations.**
- **On orbit rotating radial loads in addition to the preloads are negligible and do not exceed preloads.**
  - These are very small loads with respect to a typical dynamic load rating on a bearing
  - Suggests extremely long lifetimes at the low speeds the design is calling for
- **Launch loads on the bearings do not exceed their static load ratings to create initial damage.**
- **Lubrication to the bearings is adequate, and are maintained in clean room conditions (from bearing manufacturer) during integration**
- **CCD Row failures occur randomly and will not be concentrated in one given area**
  - Multiple adjacent rows failing is more severe degradation than rows failing in multiple isolated areas on the CCD

Reliability Assumptions - 4

- **Duty Cycles**
  - Diffuser Wheel -- 5%
  - Filter Wheel -- 10%
  - Scan Mirror Bearings -- 1%
  - Operational Heaters -- 70%
  - Survival Heaters -- 10%
  - All other components -- 100%

System Description - 1

- **Detectors**
  - Baseline - UV/VIS/NIR/SWIR Mercury Cadmium Telluride
    - 4096 rows X 4096 columns in two arrays
      - 1% row loss permitted over life for grouped array
  - Descope - UV/VIS/NIR Silicon CCD - 4096 rows X 4096 columns
      - 1% row loss permitted over life each array
- **Roll Camera**
  - Two cameras each: 3072 rows X 4096 columns
      - Substantial row loss permitted over life each array (Modeled at 2.5%)

System Description - 2

- **Electronics**
  - Processor Card -- 1 Card
  - Heater Control & H/K -- 1 Card
  - Scan Motor Control -- 1 Card
  - FSM Voice-Coil Control -- 1 Card
  - Filter Wheel Control -- 1 Card
  - Diffuser Wheel Control -- 1 Card
  - Jitter & Roll Voice Coil Control -- 1 Card
  - Power Converter -- 1 Card
  - Digitizer -- 1 Cards (Baseline)
4 Cards (Descope)
  - HAWAII ROIC Sidecar for SWIR -- 1 Device (Baseline)
  - Camera Processor & I/O -- 1 Card
- **ACS**
  - IMU -- 1 Astrix 200
  - Star Tracker -- µASC, 2 heads, 1processor

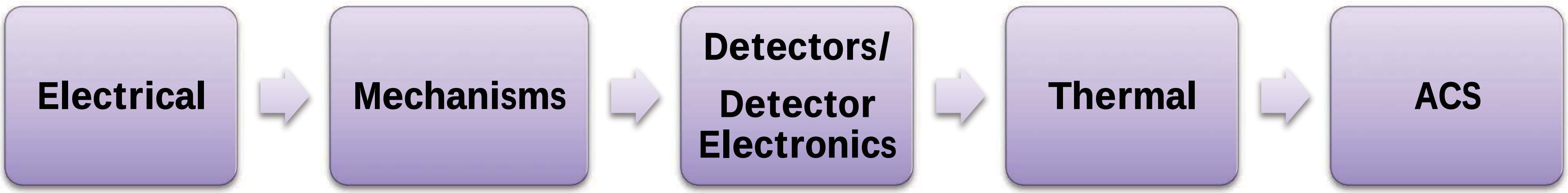
System Description - 3

- **Mechanisms**
  - Diffuser Wheel
    - Stepper Motor
    - Encoder
    - Gear Set
  - Scan Mirror
    - 2 axes each with:
      - Torquer Motor (Frameless)
      - 24 bit Encoder
      - Mechanism Bearings (2)
  - Fast Scan Mirror – 2 axes each with:
    - 2 Voice Coil actuators
    - 2 LVDT position detectors
  - Filter Wheels
    - 2 Stepper Motors
    - 2 Encoders
    - 2 Gear Sets
    - Optical Switches (20)
    - Filter Wheel Bearings (30)
  - Jitter Suppression/Roll Correction
    - 3 Flexure Mounts (not modeled)
    - 3 Voice Coil Actuators
  - Contamination Door
    - Redundant HOP actuators each with Redundant Heaters

System Description - 4

- **Thermal**
  - 12 Thermistor controlled redundant Operational Heater Circuits (Baseline & Descope)
  - 1 Thermostat controlled redundant Operational Heater Circuits
  - 13 Thermostat controlled redundant Survival Heater Circuits
  - 2 Redundant heat pipes

GEO-CAPE FR Reliability Block Diagram

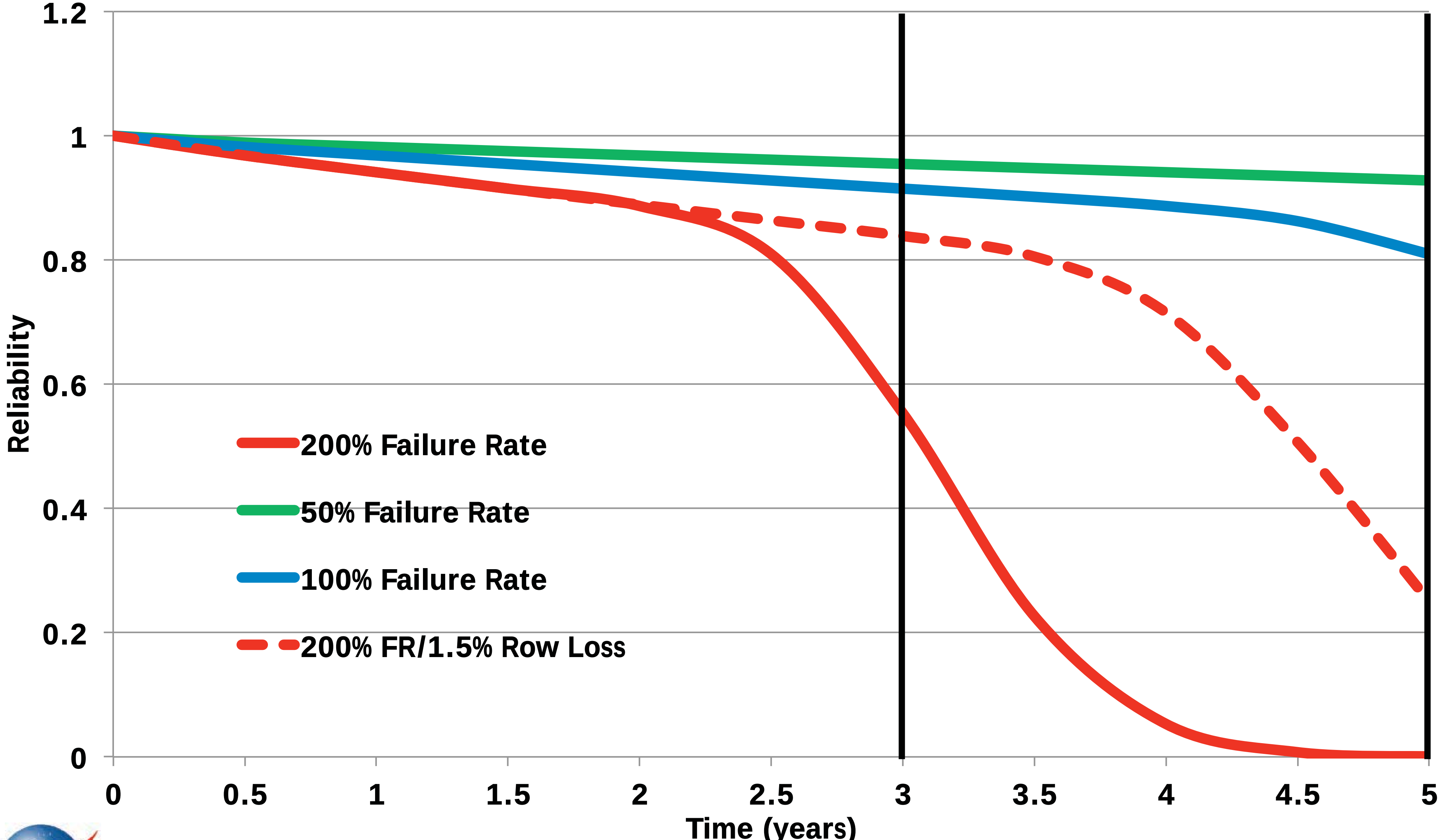


Instrument Reliability Summary

	Baseline		Descope	
	Years on Orbit		Years on Orbit	
	3	5	3	5
Detectors-Detector Electronics	0.9852	0.9141	0.9748	0.8001
Electrical	0.9594	0.9333	0.9594	0.9333
Mechanisms	0.9760	0.9621	0.9760	0.9621
ACS	0.9919	0.9865	0.9919	0.9865
Thermal	0.9997	0.9995	0.9997	0.9995

Design Reliability	0.9151	0.8096	0.9052	0.7083

Reliability Boundary Limits (Baseline)



Conclusions and Recommendations

- Design exceeds required 85% reliability for 3 years (91.5% for Baseline & 90.5% for Descope Configuration), and actually exceeds 80% for 5 years (81.0% for Baseline Configuration)
  - Lower Boundary Limit (200% Failure Rate) falls off dramatically at 2.5 years due to limited degradation allowed (1% of 4096 rows)
    - Increase of row loss allowance to 1.5% increases Lower Boundary Limit to 83.9% at 3 years
- Assure all assemblies (in- and out-of-house) have Parts Stress Analysis (PSA) and Failure Modes and Effects Analysis (FMEA) performed to assure compliance with derating and fault tolerance requirements
- Perform Probabilistic Risk Analysis (PRA) early in the program to identify high risk items and assure estimated reliability is met by designs
- Perform Worst Case Analysis (WCA) to assure part functionality over entire mission duration
- “Non-credible” Single Point Failures should be addressed with Probabilistic Risk Analysis, Failure Modes and Effects Analysis, and detailed Failure Modeling to assure they are truly “non-credible

BACKUP SLIDES

Electrical Model – All Options

Integrated Design Capability / Instrument Design Laboratory

Electrical

Subsystem / Component Name	Qty	Model	MTTF/ Char Life / Lognormal Mean	Failure Rate / Shape / Lognormal Std Dev	Relative Duty Cycle	Component Reliability (for time in years)			Redundancy Configuration	Subsytem Reliability (for time in years)		
						3	5	5		3	5	5
Main Electrical Box	1				100%	0.959434053	0.933308486	0.933308486	Single String	0.959434053	0.933308486	0.933308486
Processor	1	E	1824485	5.481E-07		0.985699174	0.976279089	0.976279089	Single String	0.959434053	0.933308486	0.933308486
LVPS	1	E	4865292	2.0554E-07		0.994613036	0.991037859	0.991037859				
Diffuser Wheel Stepper Motor Control	1	E	7297938	1.3703E-07		0.996405459	0.994016279	0.994016279				
Heater Control and H/K	1	E	7297938	1.3703E-07		0.996405459	0.994016279	0.994016279				
Fast Steering Mirror Voice Coil Actuator	1	E	7297938	1.3703E-07		0.996405459	0.994016279	0.994016279				
Jitter & Roll Comp. Voice Coil Actuator	1	E	7297938	1.3703E-07		0.996405459	0.994016279	0.994016279				
Scan Mirror Card	1	E	7297938	1.3703E-07		0.996405459	0.994016279	0.994016279				
Filter Wheel Stepper Motor Control Card	1	E	7297938	1.3703E-07		0.996405459	0.994016279	0.994016279				

	Electrical Total		
	3 years	5 years	5 years
Min Redundancy	0.959434053	0.933308486	0.933308486
Max Redundancy	0.959434053	0.933308486	0.933308486

Mechanisms Model – All Options

Mechanisms

Subsystem / Component Name	Qty	Model	MTTF/ Char Life / Lognormal Mean	Failure Rate / Shape / Lognormal Std Dev	Relative Duty Cycle	Component Reliability (for time in years) 3	5	5	Redundancy Configuration	Subsytem Reliability (for time in years) 3	5	5
Filter Wheel Mechanism	1				10%	0.998604538	0.997190046	0.997190046	Single String	0.998604538	0.997190046	0.997190046
Motor Winding	2	E	5000000	0.0000002		0.998949352	0.998249534	0.998249534	Single String	0.998604538	0.997190046	0.997190046
Motor Bearings	4	W	100000	3.5		0.999988231	0.99992966	0.99992966				
Resolver	2	E	76923076	1.3E-08		0.999931674	0.999886126	0.999886126				
Gear set	2	W	250000	2		0.99977902	0.999386288	0.999386288				
Mechanism Bearings	15	W	100000	3.5		0.999955866	0.999736249	0.999736249				
Scan Mirror Mechanism (SMM) Bearings	1				1%	0.999999996	0.999999978	0.999999978	Single String	0.999999996	0.999999978	0.999999978
Mechanism Bearings	4	W	100000	3.5		0.999999996	0.999999978	0.999999978	Single String	0.999999996	0.999999978	0.999999978
Scan Mirror Mechanism (SMM) Electrical	1				100%	0.988867154	0.981514198	0.981514198	Single String	0.988867154	0.981514198	0.981514198
Motor Winding	2	E	5000000	0.0000002		0.989543058	0.982632583	0.982632583	Single String	0.988867154	0.981514198	0.981514198
Encoder	2	E	76923076	1.3E-08		0.999316953	0.998861848	0.998861848				
Fast Steering Mirror (FSM)	1				100%	0.997113374	0.995193588	0.995193588	Single String	0.997113374	0.995193588	0.995193588
Voice Coil	4	E	50000000	0.00000002		0.997899808	0.996502132	0.996502132	Single String	0.997113374	0.995193588	0.995193588
LVDT	4	E	133333333	7.5E-09		0.999211911	0.998686863	0.998686863				
Vibration Suppression System Locks	3				100%	0.98	0.98	0.98	Hot Redundancy	0.99880048	0.99880048	0.99880048
Frangibolt	1	U				0.98	0.98	0.98	Hot Redundancy	0.99880048	0.99880048	0.99880048
Contamination Door	1				100%	0.95	0.95	0.95	Hot Redundancy	0.9975	0.9975	0.9975
HOP	1	U				0.95	0.95	0.95	Hot Redundancy	0.9975	0.9975	0.9975
Vibration Suppression System - Active	1				100%	0.998424442	0.99737545	0.99737545	Single String	0.998424442	0.99737545	0.99737545
Voice Coil	3	E	50000000	0.00000002		0.998424442	0.99737545	0.99737545	Single String	0.998424442	0.99737545	0.99737545
Diffuser Wheel	1				5%	0.9996915	0.999450726	0.999450726	Single String	0.9996915	0.999450726	0.999450726
Motor Winding	1	E	5000000	0.0000002		0.999737235	0.999562096	0.999562096	Single String	0.9996915	0.999450726	0.999450726
Motor Bearings	2	W	100000	3.5		0.99999948	0.999996891	0.999996891				
Mechanism Bearings	2	W	100000	3.5		0.99999948	0.999996891	0.999996891				
Resolver	1	E	76923076	1.3E-08		0.999982918	0.99997153	0.99997153				
Gear set	1	W	250000	2		0.999972375	0.999923265	0.999923265				
Filter Wheels Optical Switches	10				100%	0.999843909	0.999739862	0.999739862	Single String	0.998440186	0.997401662	0.997401662
LED	1	E	4.167E+09	2.4E-10		0.999993693	0.999989488	0.999989488	Single String	0.998440186	0.997401662	0.997401662
Photodetector (1 pixel)	1	E	175438596	5.7E-09		0.999850215	0.999750371	0.999750371				

Mechanisms Total	3 years	5 years	5 years
Min Redundancy	0.977621919	0.964859054	0.964859054
Max Redundancy	0.977621919	0.964859054	0.964859054

Detector – Detector Electronics Model Baseline

Detectors

Subsystem / Component Name	Qty	Model	MTTF/ Char Life / Lognormal Mean	Failure Rate / Shape / Lognormal Std Dev	Relative Duty Cycle	Component Reliability (for time in years) 3	5	5	Redundancy Configuration	Subsytem Reliability (for time in years) 3	5	5
										3000	of	3072
Roll Camera	2				100%	0.994757789	0.991278257	0.991278257	K of N (Hot)	1	1	1
CMOS 1K Row	4	E	20000000	0.00000005		0.994757789	0.991278257	0.991278257	K of N (Hot)	1	1	1
										3000	of	3072
Detector Electronics	1				100%	0.996156727	0.993602755	0.993602755	Single String	0.996156727	0.993602755	0.993602755
HAWAII ROIC	1	E	1.05E+08	9.5E-09		0.999750371	0.999583987	0.999583987	Single String	0.996156727	0.993602755	0.993602755
Digitizer	1	E	7297938	1.3703E-07		0.996405459	0.994016279	0.994016279				
Roll Camera Electronics	2				100%	0.996405459	0.994016279	0.994016279	Single String	0.992823838	0.988068363	0.988068363
Electronics in Camera	1	E	7297938	1.3703E-07		0.996405459	0.994016279	0.994016279	Single String	0.992823838	0.988068363	0.988068363
										4055	of	4096
MERCAD Detector Array	1				100%	0.995217998	0.992042708	0.992042708	K of N (Hot)	0.999993086	0.937038065	0.937038065
MERCAD Photodetector (1 pixel)	4096	E	2.25E+10	4.4531E-11		0.995217998	0.992042708	0.992042708	K of N (Hot)	0.999993086	0.937038065	0.937038065
										4055	of	4096
Roll Camera Interface	1				100%	0.996405459	0.994016279	0.994016279	Single String	0.996405459	0.994016279	0.994016279
Processor/I-O Card	1	E	7297938	1.3703E-07		0.996405459	0.994016279	0.994016279	Single String	0.996405459	0.994016279	0.994016279

	Detectors Total		
	3 years	5 years	5 years
Min Redundancy	0.985446302	0.914430096	0.914430096
Max Redundancy	0.985446302	0.914430096	0.914430096

Detector – Detector Electronics Model Descope

Detectors-Detector Electronics

Subsystem / Component Name	Qty	Model	MTTF/ Char Life / Lognormal Mean	Failure Rate / Shape / Lognormal Std Dev	Relative Duty Cycle	Component Reliability (for time in years) 3	5	5	Redundancy Configuration	Subsytem Reliability (for time in years) 3	5	5
										4055	of	4096
CCD Detector Array	1				100%	0.994757789	0.991278257	0.991278257	K of N (Hot)	0.999945641	0.834759685	0.834759685
CCD 1K Row	4	E	20000000	0.00000005		0.994757789	0.991278257	0.991278257	K of N (Hot)	0.999945641	0.834759685	0.834759685
										4055	of	4096
										3000	of	3072
Roll Camera	2				100%	0.994757789	0.991278257	0.991278257	K of N (Hot)	1	1	1
CMOS 1K Row	4	E	20000000	0.00000005		0.994757789	0.991278257	0.991278257	K of N (Hot)	1	1	1
										3000	of	3072
Detector Electronics	1				100%	0.985453115	0.975872945	0.975872945	Single String	0.985453115	0.975872945	0.975872945
ROIC	1	E	1.05E+08	9.5E-09		0.999750371	0.999583987	0.999583987	Single String	0.985453115	0.975872945	0.975872945
Digitizer	4	E	7297938	1.3703E-07		0.985699174	0.97627909	0.97627909				
Roll Camera Electronics	2				100%	0.996405459	0.994016279	0.994016279	Single String	0.992823838	0.988068363	0.988068363
Electronics in Camera	1	E	7297938	1.3703E-07		0.996405459	0.994016279	0.994016279	Single String	0.992823838	0.988068363	0.988068363
Roll Camera Interface	1				100%	0.996405459	0.994016279	0.994016279	Single String	0.996405459	0.994016279	0.994016279
Processor/I-O Card	1	E	7297938	1.3703E-07		0.996405459	0.994016279	0.994016279	Single String	0.996405459	0.994016279	0.994016279

	tors-Detector Electronics		
	3 years	5 years	5 years
Min Redundancy	0.97481152	0.800083354	0.800083354
Max Redundancy	0.97481152	0.800083354	0.800083354

Thermal Model – All Options

Thermal

Subsystem / Component Name	Qty	Model	MTTF/ Char Life / Lognormal Mean	Failure Rate / Shape / Lognormal Std Dev	Relative Duty Cycle	Component Reliability (for time in years) 3	5	5	Redundancy Configuration	Subsytem Reliability (for time in years) 3	5	5
Operational Heaters	12				70%	0.999983575	0.999972625	0.999972625	Single String	0.999802919	0.999671554	0.999671554
Redun Htr/T-Stat Ckt	1	E	1.12E+09	8.9286E-10		0.999983575	0.999972625	0.999972625	Single String	0.999802919	0.999671554	0.999671554
Survival Heaters	13				10%	0.999997654	0.999996089	0.999996089	Single String	0.999969497	0.999949162	0.999949162
Redun Htr/T-Stat Ckt	1	E	1.12E+09	8.9286E-10		0.999997654	0.999996089	0.999996089	Single String	0.999969497	0.999949162	0.999949162
										33	of	34
Thermistors	1				100%	0.9999429	0.999904835	0.999904835	K of N (Hot)	0.999998173	0.99999493	0.99999493
Thermistors	1	E	4.6E+08	2.1728E-09		0.9999429	0.999904835	0.999904835	K of N (Hot)	0.999998173	0.99999493	0.99999493
										33	of	34
Controlled Heaters	1				70%	0.992628929	0.987745092	0.987745092	Hot Redundancy	0.999945667	0.999849817	0.999849817
Heater	1	E	2500000	0.0000004		0.992668607	0.987810896	0.987810896	Hot Redundancy	0.999945667	0.999849817	0.999849817
thermistor	1	E	4.6E+08	2.1728E-09		0.99996003	0.999933384	0.999933384				
Heat Pipes	2				100%	0.99957	0.999283436	0.999283436	Hot Redundancy	0.99999963	0.999998973	0.999998973
fixed conductance heat pipe (FCHP)	1	E	61103138	1.6366E-08		0.99957	0.999283436	0.999283436	Hot Redundancy	0.99999963	0.999998973	0.999998973

	Thermal Total 3 years	5 years	5 years
Min Redundancy	0.999715906	0.999464513	0.999464513
Max Redundancy	0.999715906	0.999464513	0.999464513

ACS Model – All Options

Integrated Design Capability / Instrument Design Laboratory

ACS

Subsystem / Component Name	Qty	Model	MTTF/ Char Life / Lognormal Mean	Failure Rate / Shape / Lognormal Std Dev	Relative Duty Cycle	Component Reliability (for time in years)			Redundancy Configuration	Subsytem Reliability (for time in years)		
						3	5	5		3	5	5
Star Tracker	1				100%	0.994862363	0.991451944	0.991451944	Single String	0.994862363	0.991451944	0.991451944
Star Tracker Head (Mini Star Tracker)	2	E	38461538	0.000000026		0.998634373	0.997724992	0.997724992	Single String	0.994862363	0.991451944	0.991451944
Star Tracker Processor (Mini Star Tracker)	1	E	6944444.4	0.000000144		0.996222832	0.993712649	0.993712649				
IMU	1				100%	0.996996993	0.995	0.995	Single String	0.996996993	0.995	0.995
Astrix 200	1	E	8738081.7	1.14442E-07		0.996996993	0.995	0.995	Single String	0.996996993	0.995	0.995

ACS Total	3 years	5 years	5 years
Min Redundancy	0.991874784	0.986494684	0.986494684
Max Redundancy	0.991874784	0.986494684	0.986494684

GEO CAPE Filter Radiometer (FR)

~ Concept Presentations ~

Parametric Cost

Sanjay Verma

September 8, 2014

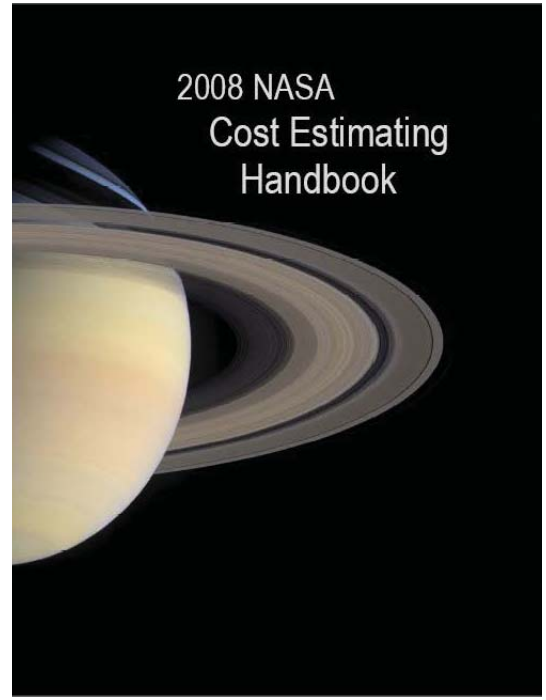
NASA Cost Estimating Overview

NASA Cost Estimating Handbook 2008

- Defines three cost estimating Methodologies
  - **Parametric**: based on key engineering data and Cost Estimating Relationships (CERs)
  - **Analogy**: comparison and extrapolation to like items or efforts
  - Engineering Build-Up (i.e., "**grass-roots**"): Labor and Material estimates based on experience and "professional judgment"
- Defines two cost estimating Processes
  - **Advocacy Cost Estimates (ACE)**
    - Cost Estimators are members of program/project team
  - **Independent Cost Estimates (ICE)**
    - Cost Estimators are from an organization separate from project
- Encourages parametric modeling and analogy estimates during pre-Phase A and Phase A studies

http://www.nasa.gov/offices/ooe/CAD.html

http://ceh.nasa.gov



Proposal cost estimates evaluated at NASA Langley Research Center during Technical, Management, and Cost (TMCO) review

- Parametric models used to validate proposal cost estimate
- Assumed criteria for validation of Step 1 proposal (based on feedback): proposal estimate and TMCO consensus estimate within 20%

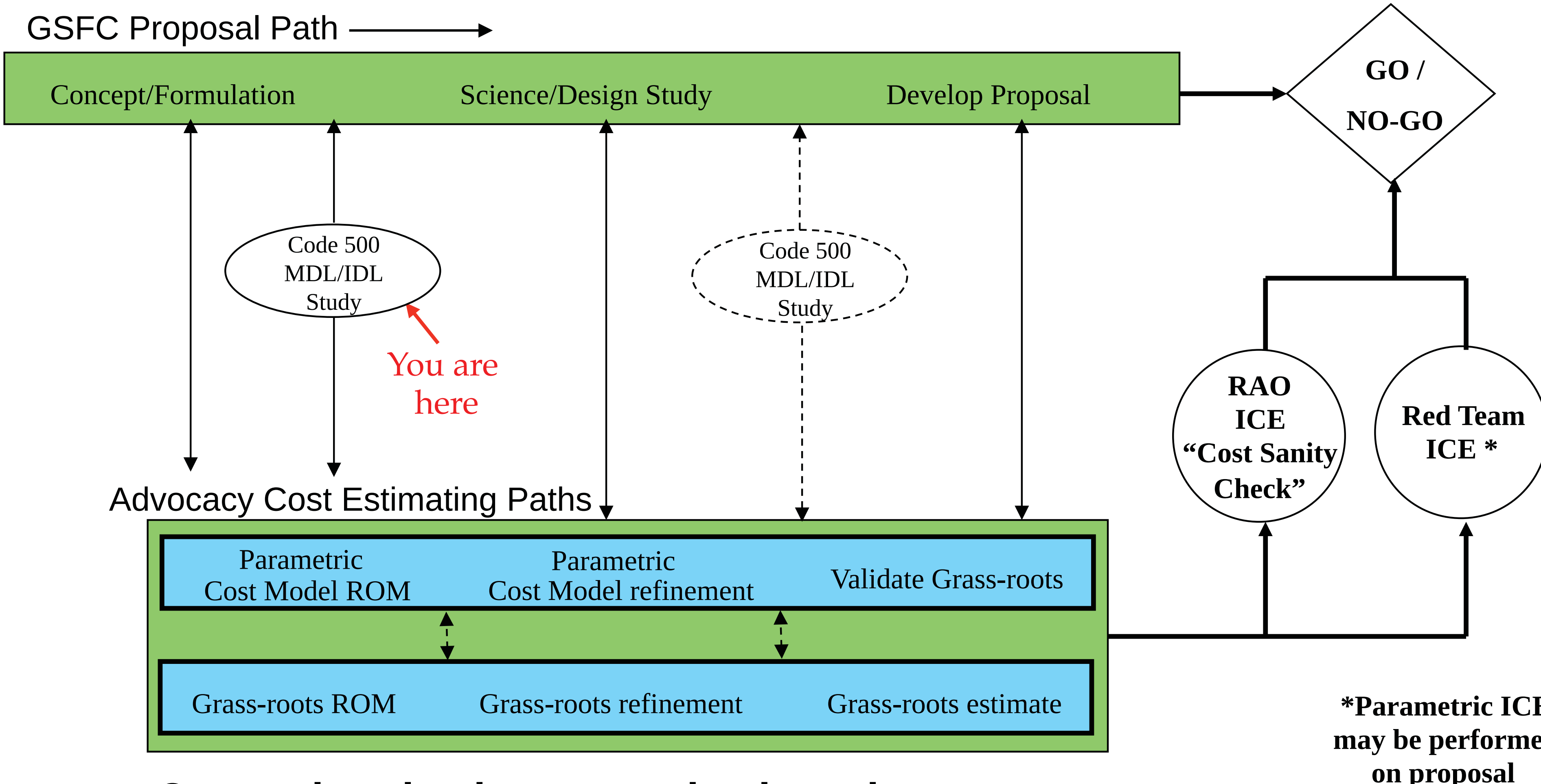
Current GSFC Proposal Cost Estimating "Best Practices"

- **Advocacy Cost Estimating**
  - **Proposal Teams**
    - Grassroots estimate based on Work Breakdown Structure (WBS)
    - Parametric modeling used for Grassroots validation
  - **IDC**
    - Parametric modeling used to generate a stand-alone cost estimate
    - No Grassroots (WBS) cost estimate to validate

- **Independent "Assessment" (provided by RAO)**
  - Internal cost estimating tools and historical databases
  - Provides critical "Sanity Check"

- **Evolving "Best Practices"**
  - GSFC Chief Financial Officer (CFO)
  - NASA Cost Analysis Steering Group
  - NASA Cost Estimating Handbook

Proposal Cost Estimating Process



Cost estimating is an on-going iterative process

Parametric Cost Estimating Tools

- **NASA Cost Estimating Handbook 2008 describes two commercial tools**
  - **PRICE: Parametric Review of Information for Costing and Evaluation**
    - Separate modules for Hardware, Software, Integrated Circuits, and Life Cycle
    - PRICE H (Hardware) approaches cost estimates by parametrically defining:
      - Hardware to be built
      - Development and manufacturing environments
      - Operational environment
      - Schedule
    - PRICE H model is built from key engineering data (e.g., MEL: Master Equipment List)
    - Tool Heritage: Developed by RCA in the 1960's for the U.S. NAVY, Air force & NASA; Commercialized by PRICE Systems, L.L.C.
    - NASA-wide site license for PRICE H managed by Langley Research Center

      (GSFC Contact: Dedra Billings, Code 305.0, e-mail: Dedra.S.Billings@nasa.gov)
    - PRICE H use at GSFC:
      - Mission Design Lab (MDL/IMDC), 10+ years experience and 150+ S/C Bus models
      - Instrument Design Lab (IDL/ISAL), 8+ years experience and 120+ Instrument models
      - Code 600/158, 10+ years experience, 100+ S/C Bus and 100+ Instrument models
  - **SEER: System Evaluation & Estimation of Resources**
    - Separate modules for Hardware, Software, Integrated Circuits, Manufacturability and Life Cycle
    - NASA-wide site license for SEER managed by Langley Research Center
    - Application-specific use of SEER-H at GSFC (e.g., detectors, cryocoolers, etc.)
    - SEER-SEM at GSFC used for estimating FSW w/ SLOC

PRICE H: Key Input Parameters

- **Global Parameters:**
  - Labor Rates (set as appropriate)
    - GSFC Bid Rates ← FSW for This Study
    - This Study → GSFC Typical Contractor Rates
      - Used for GSFC vendor provided hardware
      - Used when actual rates are not available
      - 10% G&A, 14% Fee
    - PRICE H Industry Labor Rates (default labor rates provided by Price Systems, Inc.)
      - ?% G&A, ?% Fee
  - Inflation (NASA escalation rates)
  - Engineering Environment (Defined for NASA by PRICE Systems, Inc. calibration study)
    - Emphasizes: System Engineering, Project Management, Automated design capabilities
- **Individual Cost Component Parameters:**
  - Complexity Factors (Table driven, defined by Price Systems from industry experience)
  - Modification Level/Remaining Design Factor (Heritage)
  - Quantity and Design Repeat (Learning Curve)
  - Composition (Structure, Electronic, Purchased, Cost Pass-through)
  - Mass
  - Operating Platform (Unmanned Space – High Reliability)

IDL Parametric Cost Modeling

- **GEO CAPE FR Parametric Cost Inputs :**
  - IDL Discipline Engineering Final Presentations
  - Master Equipment List (MEL)

- **GEO CAPE WAS Grassroots Cost Inputs:**
  (provided by IDL Discipline Engineers)
  - IDL provided grassroots cost estimates for:
    - FPGA Firmware (see MEL FPGA tab and Final Electrical Presentation) – Escalated to FY$16
    - FSW Testbed (see MEL FSW tabs and Final FSW Presentation)
    - SideCar ASIC Assembly Code (see MEL ASIC Code tab and Final FSW Presentation)
    - Nickel Plating NRE - Optics

- **GEO CAPE WAS Cost Output Customer Products:**
  - PowerPoint presentation
  - Model results exported to Excel Spreadsheet and merged with grassroots costs (if any) and appropriate GSFC wrap factors
    - Excel output spreadsheet includes multiple tabs (at bottom)

GEO CAPE FR
Cost Modeling Key Assumptions

- **GEO CAPE FR Key Assumptions:**
  - ETUs and Component Spares covered by wrap factors
  - Class C Mission (Class B Parts – up-screening not included in cost estimate)
  - Costs reported in FY2016 constant year dollars
  - Instrument built by contractor – do not apply GSFC CM&O
  - FSW Estiamted using GSFC in-House bid rates
  - No existing Manufacturing Process and Assembly Line
  - PRICE-H Estimate is for a Protoflight Unit and EDUs
  - Schedule used: ATP: 12/17, CDR: 12/18, PER: 5/21
  - Detailed assumptions are tagged CME (Cost Modeler Engineered) in model
  - Minimum mass increment modeled is 3 grams. Items below 3 grams were increased to 3 grams
  - SEER-H cost estimates for CCD & HgCdTe Detectors
  - SEER-SEM cost estimates for FSW based on SLOC
  - IDL Grassroot cost estimates for FPGA firmware, FSW Testbed, SideCar ASIC Micro Code, Roll Camera repackaging, and NRE for optics with nickel plating
  - Costs not calculated by PRICE-H accounted for by GSFC calibrated placeholder 'wrap' factors:
    - Ground Support Equipment (GSE) - 5% of PRICE-H Instrument Payload Estimate
    - Environmental Testing - 5% of PRICE-H Instrument Payload Estimate
    - Component Level Flight Spares - 10% of PRICE-H Partial Instrument Payload Estimate
    - Engineering Test Units (ETUs) at subassy level – 10% of PRICE-H Partial Instrument Payload Estimate
    - Instrument to S/C Bus I&T - 5% of PRICE-H Instrument Payload Estimate (Typically Included in WBS 10.0)

GEO CAPE FR
Cost Modeling Key Assumptions

FU

- Flight Unit
  (1 for GEO CAPE FR)
- Protoflight
- "Fly the unit you qualify"
- Used for Class C mission

ETU

- Engineering Test Unit
- Hardware tested to environmental qualification levels
- May be flown as flight spare if successfully qualified
- For GEO CAPE FR : Placeholder bin of money provided via "wrap factor"
- ETUs to be determined after leaving IDL by customer team to address Gold Rule requirements and/or risk reduction
- ETUs selected by customer should be commensurate with Class C mission risk posture
- Adequacy of placeholder bin of money should be adjusted once ETU list is developed.

EDU

- Engineering Development Unit
- Can not be flown
- Used to prove out first build of early concept engineering
- Test form/function only
- Limited or no environmental testing
- For GEO CAPE FR : : EDUs selected are noted in cost detail output.
- EDU of entire instrument for consistency with other GEO CAPE studies
- Kept to minimum for Class C mission.

Spares

- Placeholder bin of money provided via "wrap factor"
- Customer should determine necessary spares at component and/or subassembly level commensurate with a Class C mission risk posture after leaving IDL
- Adequacy of placeholder bin of money should be adjusted once spares list is developed.

GEO CAPE FR Baseline
Parametric Cost Summary

Integrated Design Capability / Instrument Design Laboratory

GEOCAPE-FR Parametric Cost Estimate Summary GEOCAPE-FR Baseline Design 9/8/2014 (Development and Production Costs)	Cost Estimate (FY$16) GSFC Contractor Bid Rates Flight Units = 1 Point Estimate CBE Dry Mass (kg) 208.7	
GEOCAPE FR Instrument (Baseline Design) Assembly	**$85,707,200**	
Science Aperture Baffle Assembly		$1,402,550
Diffuser Select Assembly		$8,383,680
Scan Mirror Assembly		$8,513,334
Optical Assembly		$14,804,305
Internal Baffles Assembly		$240,115
HAWAII-4RG Detector Array Assembly		$2,239,518
Instrument Structure/Enclosure Assembly		$9,737,204
HAWAII-4RG Digitizer Box		$1,622,342
Roll Camera Assembly		$6,293,326
uASC Star Tracker		$1,927,269
IMU Assembly		$1,592,777
FR Main Electronics Box (MEB) Assembly		$15,645,364
Harness Assembly		$3,147,704
Contamination Purge Hardware (SS ,TRL 6)		$468,904
Thermal Subsystem Assembly		$5,309,597
Misc H/W		$763,421
GEOCAPE FR Instrument Assembly Integration and Test		$3,615,790
Baseline Design - Thruput Cost Estimates	**$17,227,470**	
Optical Nickel Plating NRE - IDL Grassroots Estimate		$197,523
SEER-H Estimate for 4K X 4K MCT Detector (1 Flt, 1 Sprae, and 4 EDU, FY$16 ~$17.03M)		$17,029,947
GEOCAPE-FR Parametric Estimate	**$102,934,669**	
The Following are NOT PRICE-H estimates but are derived from PRICE-H estimates. These are included for completeness and are considered ROM 'Grass-roots' estimates. Consult the Grass-roots estimating organization for a more accurate estimate.		
Flight Software (SEER-SEM SLCO Based Parametric Estimate, incl sustaining Eng., GSFC In-House Bid Rates)	**$4,308,528**	
FSW Test-Bed (IDL Grassroots Estimate)	**$899,175**	
FPGA development (IDL Grassroots Estimate, 6 Unique FPGA @ & 6 Unique Algorithms @ ~$451K ea)	**$5,415,840**	
ASIC Development (IDL Grassroots Estimate, Baseline Design SIDECAR Modification)	**$1,628,917**	
Ground Support Equipment (GSE) (5% of Parametric Estimate)	**$5,146,733**	
Environmental Testing Labor (5% of Parametric Estimate)	**$5,146,733**	
Engineering Test Unit (ETU, 10% of Parametric Estimate)	**$10,293,467**	
H/W Spares (10% of Parametric Estimate)	**$10,293,467**	
Instrument to SC-BUS I&T (5% of Parametric Estimate, Typically included in NASA WBS 10.0)	**$5,146,733**	
GEOCAPE-FR Subtotal	**$151,214,263**	
Institutional Charges (Basis of Estimate: AO Guidance of $43K/FTE, GSFC CM&O) (For GSFC, Contact Code 153 to verify applicability to your project)	**N/A**	
GEOCAPE-FR Total	**$151,214,263**	

GEOCAPE FR Descoped Design Parametric Cost Summary

GEOCAPE-FR Parametric Cost Estimate Summary GEOCAPE-FR Descope Design 9/8/2014 (Development and Production Costs)	Cost Estimate (FY$16) GSFC Contractor Bid Rates Flight Units = 1 Point Estimate CBE Dry Mass (kg) 208.7	
GEOCAPE FR Instrument (Descope) Assembly	**$85,066,205**	
Science Aperture Baffle Assembly		$1,402,550
Diffuser Select Assembly		$8,383,680
Scan Mirror Assembly		$8,513,334
Optical Assembly		$14,804,305
Internal Baffles Assembly		$240,115
UV-VIS-NIR Silicon Detector Array Assembly		$1,076,254
Instrument Structure/Enclosure Assembly		$9,737,204
Digitizer Box		$2,291,074
Roll Camera Assembly		$6,293,326
uASC Star Tracker		$1,927,269
IMU Assembly		$1,592,777
FR Main Electronics Box (MEB) Assembly		$15,645,364
Harness Assembly		$3,142,707
Contamination Purge Hardware (SS ,TRL 6)		$468,904
Thermal Subsystem Assembly		$5,043,883
Misc H/W		$763,478
GEOCAPE FR Instrument Assembly Integration and Test		$3,739,981
Descope Design - Thruput Cost Estimates	**$9,111,233**	
Optical Nickel Plating NRE - IDL Grassroots Estimate		$197,523
SEER-H Estimate for 4K X 8K CCD Detector (FY$16 ~$8.91M)		$8,913,710
GEOCAPE-FR Parametric Estimate	**$94,177,437**	
The Following are NOT PRICE-H estimates but are derived from PRICE-H estimates. These are included for completeness and are considered ROM 'Grass-roots' estimates. Consult the Grass-roots estimating organization for a more accurate estimate.		
Flight Software (SEER-SEM SLCO Based Parametric Estimate, incl sustaining Eng., GSFC In-House Bid Rates)	**$4,308,528**	
FSW Test-Bed (IDL Grassroots Estimate)	**$899,175**	
FPGA development (IDL Grassroots Estimate, 6 Unique FPGA @ & 6 Unique Algorithms @ ~$451K ea)	**$5,415,840**	
Ground Support Equipment (GSE) (5% of Parametric Estimate)	**$4,708,872**	
Environmental Testing Labor (5% of Parametric Estimate)	**$4,708,872**	
Engineering Test Unit (ETU, 10% of Parametric Estimate)	**$9,417,744**	
H/W Spares (10% of Parametric Estimate)	**$9,417,744**	
Instrument to SC-BUS I&T (5% of Parametric Estimate, Typically included in NASA WBS 10.0)	**$4,708,872**	
GEOCAPE-FR Subtotal	**$137,763,083**	
Institutional Charges (Basis of Estimate: AO Guidance of $43K/FTE, GSFC CM&O) (For GSFC, Contact Code 153 to verify applicability to your project)	**N/A**	
GEOCAPE-FR Total	**$137,763,083**	

GEOCAPE FR Baseline
PRICE-H Cost Summary

Basic Estimate (Metric)

Cost Summary | LM Totals | LM Production | LM Development

GEOCAPE FR Instrument Assembly
Mon September 08 2014 4:10 PM (PRICE Estimating Suite 2014A Beta)
Assembly Cost — Costs in ($1000 Constant 2016)

Program Cost	Development	Production	Total Cost
Engineering			
Draft	5337.1	452.7	5789.9
Design	21857.2	2372.0	24229.2
System	7428.5	-	7428.5
Proj. Mgmt.	8438.7	5115.7	13554.5
Data	123.7	95.5	219.3
SubTotal(ENG)	43185.3	8036.0	51221.3
Des Int Cost	[1308.1]		
Manufacturing			
Production	-	7488.3	7488.3
Prototype	2977.2	-	2977.2
Tool Test Eq.	406.4	142.8	549.2
Purchased	2439.8	4497.7	6937.4
SubTotal(MFG)	5823.4	12128.7	17952.1
G & A / CoM	4556.5	1451.9	6008.3
Fee / Profit	7499.1	3026.3	10525.4
Total Cost	61064.3	24642.9	85707.2
System Total	61064.3	24642.9	85707.2
Schedule Start	Dec 17 [16]	Dec 18 [14]	
First Item	Mar 19	Jan 20 [16]	
Finish	Mar 19 [16]	May 21 [30]	

Assy Weight	208.66	Assy WS	199.36
Assy Series MTBF Hrs	326.149	Unit Assy Cost	14398036.60
Assy Quantity	1	Avg Assy Cost	24642915.56

Engineering

Project Management

Manufacturing

Schedule

Mass

Cost Element (Summary Report Available for each cost element)

Constant Year Dollars ($16)

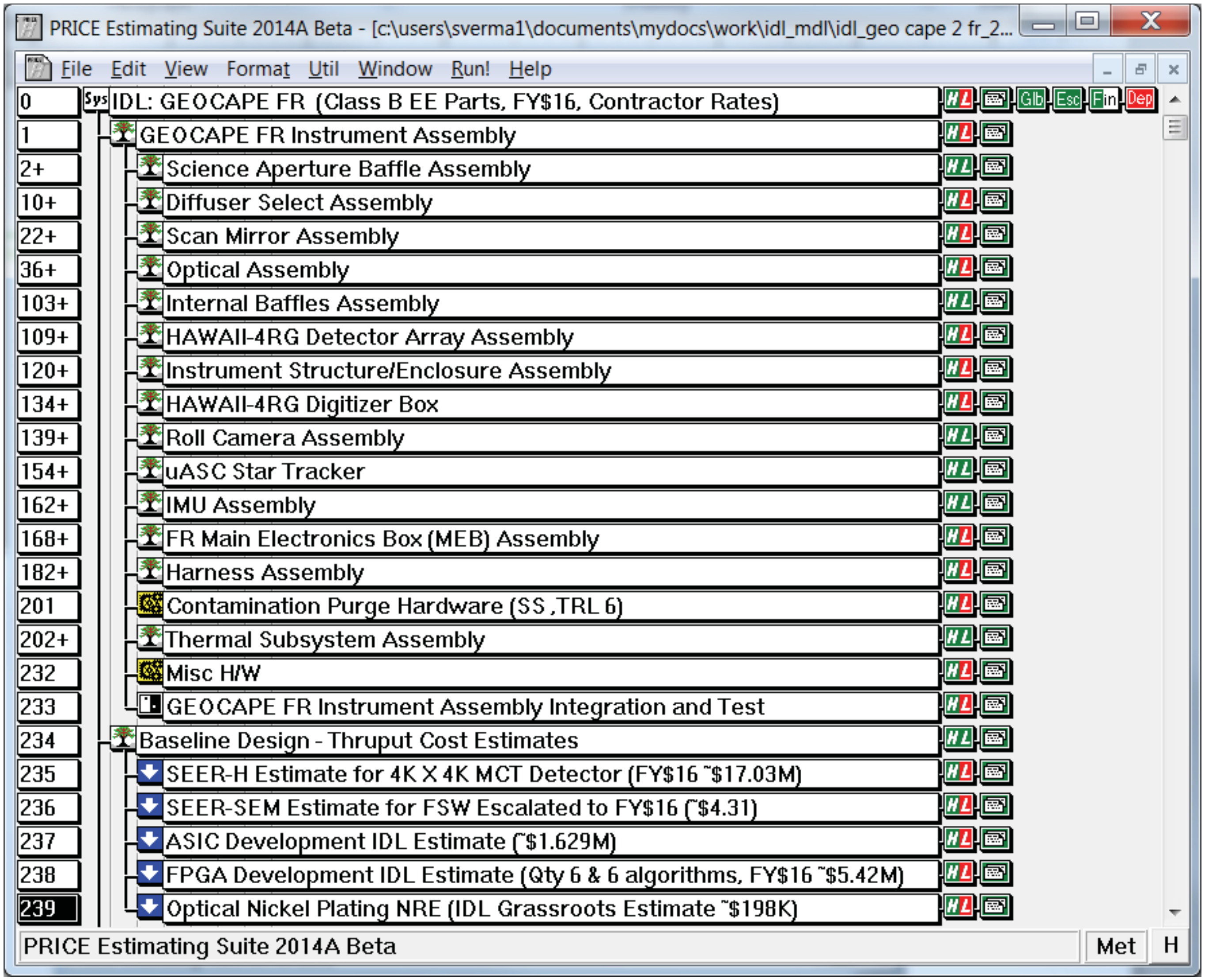
Production

Development

PRICE-H Instrument Development and Production Cost Estimate ~$85.7M

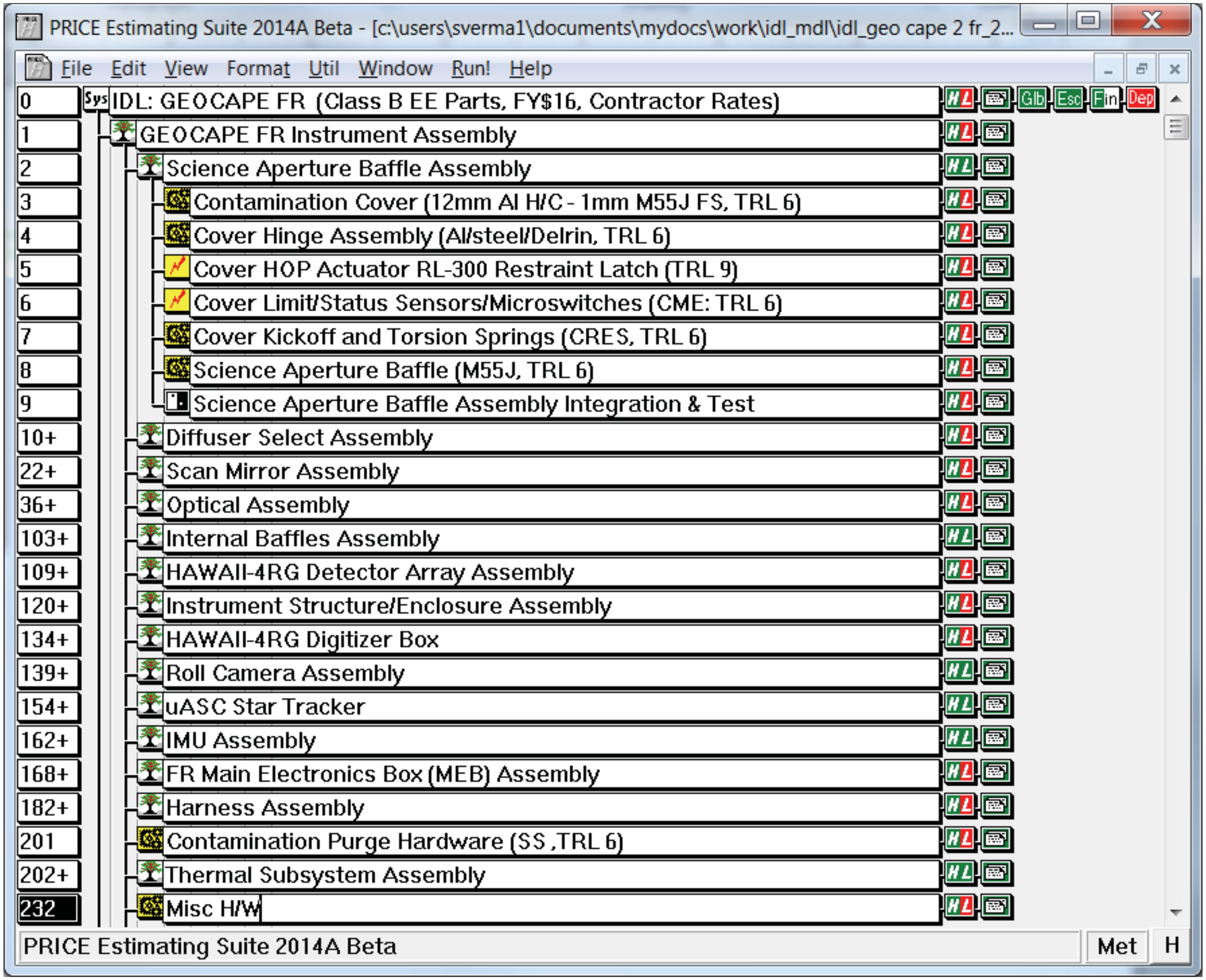
GEOCAPE FR Baseline
PRICE-H Top-Level Cost Model

Integrated Design Capability / Instrument Design Laboratory



GEOCAPE FR Baseline
Expanded PRICE-H Model

Integrated Design Capability / Instrument Design Laboratory



GEO CAPE WAS Baseline
PRICE-H Detailed Cost Estimate

Integrated Design Capability / Instrument Design Laboratory

Indenture	Title	QTY	QNA	Unit Mass	Total Mass (Kg)	Est Total Cost	Mode
1	GEOCAPE FR (Baseline Design) Instrument Assembly	1	1		208.660	$85,707,200	Assembly
2	***Science Aperture Baffle Assembly***	1	1			$1,402,550	Assembly
3	*Contamination Cover (12mm Al H/C - 1mm M55J FS, TRL 6)*	1	1	1.000	1.000	$274,752	STRUCTURAL / MECHANICAL
3	*Cover Hinge Assembly (Al/steel/Delrin, TRL 6)*	1	1	1.000	1.000	$247,155	STRUCTURAL / MECHANICAL
3	*Cover HOP Actuator RL-300 Restraint Latch (TRL 9)*	1	1	0.280	0.280	$76,622	ELECTRO / MECHANICAL
3	*Cover Limit/Status Sensors/Microswitches (CME: TRL 6)*	1	1	0.100	0.100	$244,441	ELECTRO / MECHANICAL
3	*Cover Kickoff and Torsion Springs (CRES, TRL 6)*	1	1	0.500	0.500	$173,088	STRUCTURAL / MECHANICAL
3	*Science Aperture Baffle (M55J, TRL 6)*	1	1	1.100	1.100 3.980	$320,866	STRUCTURAL / MECHANICAL
3	*Science Aperture Baffle Assembly Integration & Test*	1	1		3.980	$65,626	INTEG & TEST
2	***Diffuser Select Assembly***	1	1			$8,383,680	Assembly
3	*Diffuser Wheel Edge Cover (Qty 2, M55J, TRL 6)*	2	2	0.170	0.340	$114,463	STRUCTURAL / MECHANICAL
3	*Diffuser Wheel (Al H/C - AL FS, TRL 6)*	1	1	4.000	4.000	$850,537	STRUCTURAL / MECHANICAL
3	*Drive Ring (Al, TRL 6)*	1	1	7.500	7.500	$1,931,445	STRUCTURAL / MECHANICAL
3	*Diffuser-1 (Fused Silica, TRL 6)*	1	1	2.100	2.100	$951,035	STRUCTURAL / MECHANICAL
3	*Diffuser-2 (Fused Silica, TRL-6)*	1	1	2.100	2.100	$951,035	STRUCTURAL / MECHANICAL
3	*Diffuser Wheel Stepper Motor/Gearbox (TRL 6)*	1	1	2.000	2.000	$1,329,934	ELECTRO / MECHANICAL
3	*Diffuser Wheel Gearbox Pinion Gear (Steel, TRL 6)*	1	1	0.100	0.100	$68,289	STRUCTURAL / MECHANICAL
3	*Diffuser Wheel Central Bearing (Steel, TRL 6)*	1	1	0.200	0.200	$105,022	STRUCTURAL / MECHANICAL
3	*Diffuser Wheel Guide Bearing (Qty 3, Steel, TRL 6)*	3	3	0.100	0.300	$140,074	STRUCTURAL / MECHANICAL
3	*Diffuser Wheel 10 bit Absoulte Encoder (TRL 6)*	1	1	0.300	0.300 18.940	$1,286,076	ELECTRO / MECHANICAL
3	*Diffuser Select Assembly Integration & Test*	1	1		18.940	$655,770	INTEG & TEST
2	***Scan Mirror Assembly***	1	1			$8,513,334	Assembly
3	*Scan Mirror (ULE, TRL 6)*	1	1	3.637	3.637	$2,084,211	STRUCTURAL / MECHANICAL
3	*Scan Mirror Mount (M55J, TRL 6)*	1	1	2.600	2.600	$864,809	STRUCTURAL / MECHANICAL
3	*Mirror Pads (Qty 6 totaling to 6 grams, Invar, TRL-6)*	1	1	0.006	0.006	$14,342	STRUCTURAL / MECHANICAL
3	*Mirror Flexures (Qty 3 totaling to 4 grams, Ti, TRL-6)*	1	1	0.004	0.004	$17,572	STRUCTURAL / MECHANICAL
3	*Scan Mirror Mechanism Assembly*	1	1			$4,862,750	Assembly
4	Tip / Tilt Axis Limited Angle Torque Motor (Qty 2, TRL-9)	2	2	0.680	1.360	$350,720	ELECTRO / MECHANICAL
4	Tip / Tilt Axis 24 bit Absoulte Angle Encoder (Qty 2, TRL-6)	2	2	5.090	10.180	$2,494,400	ELECTRO / MECHANICAL
4	Encoder Read Heads and Interface Box (Qty 2, TRL 6)	2	2	0.254	0.508	$704,620	ELECTRO / MECHANICAL
4	Tip / Tilt Axis Bearing (Qty 4, Steel, TRL 6)	4	4	0.050	0.200	$96,875	STRUCTURAL / MECHANICAL
4	Gimbal Ring (Ti, TRL 6)	1	1	1.500	1.500	$405,812	STRUCTURAL / MECHANICAL
4	Launch Lock (Qty 2, TRL 6)	2	2	0.020	0.040 20.035	$111,916	ELECTRO / MECHANICAL
4	Scan Mirror Mechanism Assembly Integration & Test	1	1		20.035	$698,406	INTEG & TEST
3	*Scan Mirror Assembly Integration & Test*	1	1			$669,651	INTEG & TEST
2	***Optical Assembly***	1	1			$14,804,305	Assembly
3	*Aperture Stop (M55J, TRL-6)*	1	1	0.540	0.540	$305,764	STRUCTURAL / MECHANICAL
3	*M1 Assembly*	1	1			$2,369,915	Assembly
4	M1 (ULE, TRL-6)	1	1	1.265	1.265	$1,781,172	STRUCTURAL / MECHANICAL
4	M1 Pad (Qty 6, Invar, TRL-6)	6	6	0.013	0.078	$29,660	STRUCTURAL / MECHANICAL
4	M1 Flexure Blade (Qty 3, Ti, TRL 6)	3	3	0.003	0.009	$11,914	STRUCTURAL / MECHANICAL
4	M1 Mount (M55J, TRL 6)	1	1	0.750	0.750 2.642	$347,942	STRUCTURAL / MECHANICAL
4	M1 Assembly Integration & Test	1	1			$199,227	INTEG & TEST
3	*M2 Assembly*	1	1			$432,198	Assembly

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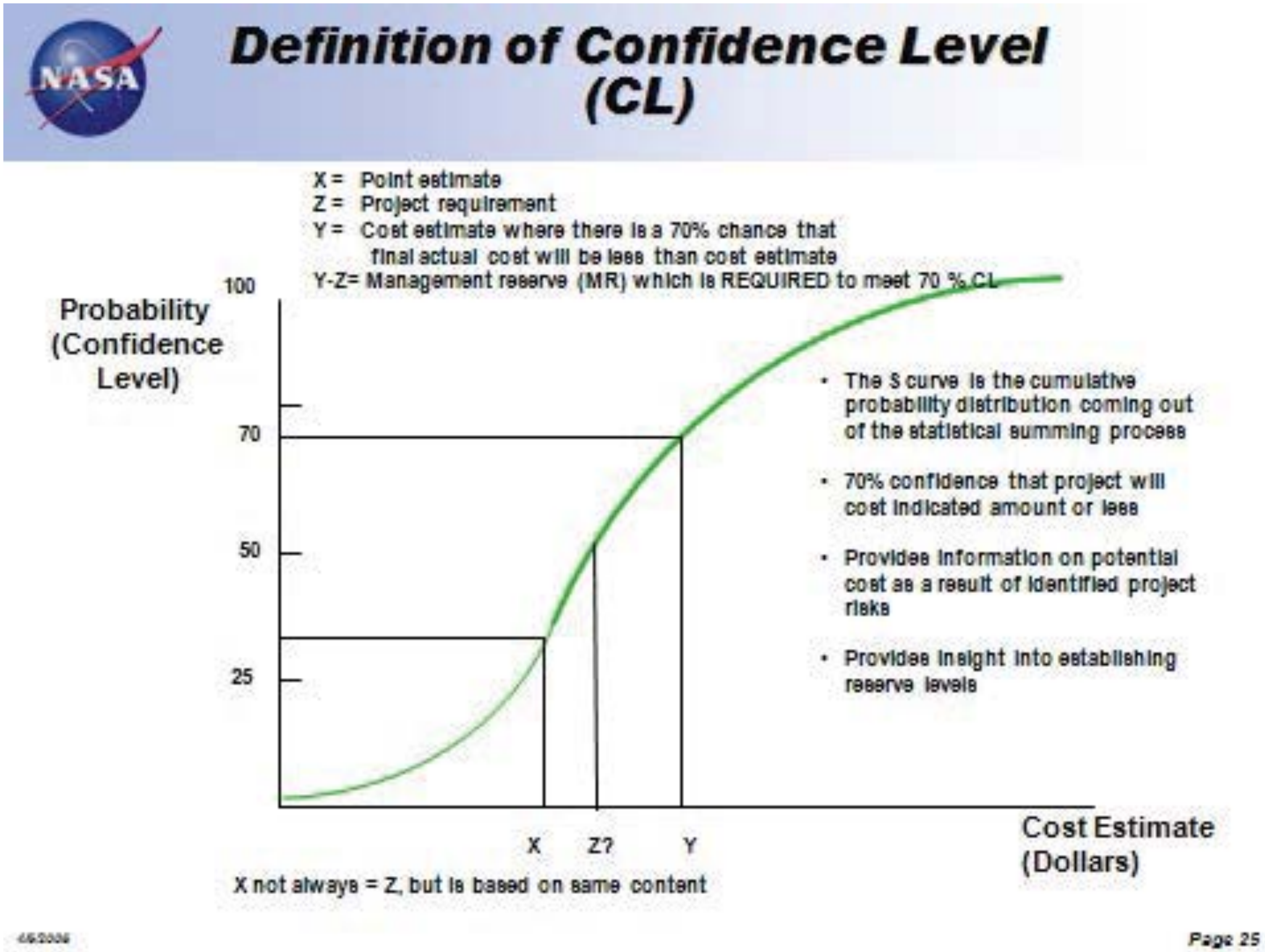
IDL Point Design Estimate & Cost Risk

Integrated Design Capability / Instrument Design Laboratory

- The IDL Cost Estimate is a Point Estimate based on the single point design of the instrument
- The point design that the IDL derives in a 1-week study is an engineering solution, but not necessarily THE solution that will be implemented for flight
- The point estimate is described by the IDL in the MEL in terms of Current Best Estimate (CBE) of mass and materials, and represents a single estimate among a range of feasible possibilities
- Cost risk analysis attempts to address the risk that the eventual outcome of the parameters may differ from the CBE selections made at the conceptual design phase of pre-formulation
- Cost risk capabilities within the parametric cost modeling tool allow a range of input values to be entered to generate a range of cost outcomes
- Cost risk simulation is performed using well known sampling techniques (e.g. Monte Carlo simulation) of the parameter ranges resulting in a Probability Distribution Function (PDF) of possible outcomes, also known as a Density Curve
- PDF can also be represented as a Cumulative Distribution Function (CDF), also known as an S-Curve to provide a graphical representation of the possibilities of various cost outcomes
- Cost risk analysis takes additional labor and is beyond a 1-week IDL study, and is not recommended for the initial IDL instrument conceptual design, but will be necessary for proposal development

Cost Confidence Level



Selected Slide, Definition of Confidence Level (CL), from “NASA Cost Risk Workshop at GSFC”.

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Recommended Future Work

1. Revisit parametric cost analysis when significant changes to mass and/or schedule are made.
2. Include costs for up-screening of Class B EEE parts
3. Project should make sure to carry Instrument contribution to WBS 10.0 (see summary).
4. Perform parametric cost-risk analysis once candidate design is close to being frozen. Bring updated ‘frozen’ MEL and charge number to Code 158 to initiate work—contact Sanjay Verma or Anthony McNair.